Chapter 3: Classification systems as tools for vegetation and habitat mapping

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Joint MNHN-EEA report

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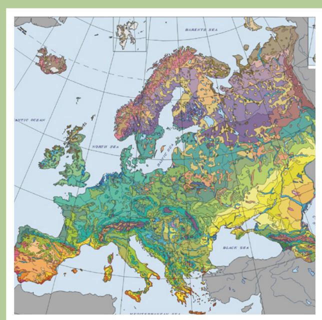

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Foreword by EEA and MNHN Directors

Identification, description, classification and mapping of natural and semi-natural habitats are gaining recognition in the sphere of environmental policy implementation. Although plant science remains at the core of the approach, habitat mapping increasingly finds applications in land planning and management and is often a necessary step in preparing nature and biodiversity conservation plans.

The vegetation in our forests, meadows, heathlands and rocky mountain slopes reflects the ecological conditions which occur in a given area, and as importantly, the changes in these conditions under environmental and human influences. A good knowledge of the condition and distribution of habitats is thus an important element to inform long-term and forward planning decision making. Key policy instruments such as the Habitats Directive and the Bern Convention implicitly address the need for habitat mapping. So does the EU 2020 Biodiversity Strategy with its aim to ensure the restoration and maintenance of ecosystems and ecosystem services.

Initiatives in Europe are numerous and diverse, ranging from local to national scales. However, information on the methodologies used and project organisation is difficult to find, especially details of project planning and finance. This report is the first review and analysis of terrestrial vegetation and habitat mapping initiatives across Europe, including the methodologies used and the project organisation. It shows the development of relevant concepts and techniques, as well as the ongoing efforts to harmonise information at the European level.

The review was originally foreseen to serve the needs of the national CARHab project on habitat mapping in France, which wanted to learn from experience elsewhere in Europe. It was led by the *Museum national d'Histoire naturelle* (MNHN) at the request of the French Ministry of Ecology, Sustainable Development and Energy. However, the review was rapidly seen by the European Environment Agency (EEA) as relevant to all European countries, and this led to the development of the present report.

This report is thus the result of a fruitful collaboration between the *Service du Patrimoine Naturel* of the MNHN — the French National Reference Centre (NRC) for biodiversity — and the EEA-European Topic Centre on Biological Diversity (ETC/BD), coordinated by the MNHN in Paris. It involved more than 70 of Europe's leading experts on habitats and vegetation who contributed to individual sections of the report. A consultation through the EEA's European information and observation network (Eionet) provided valuable additional information, particularly for countries where gaps existed.

It is a pleasure for us to recognise and promote this example of synergy between the national and European dimensions, giving full meaning to the partnership between the European Environment Agency and the European information and observation network, of which the MNHN is a key member.

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Executive summary

Vegetation mapping has a long history in Europe, with maps being produced at many scales and using a variety of typologies. Habitat mapping is more recent, and has increased greatly as a result of the need for information necessary to implement the 1992 European Union Habitats Directive. In view of the implementation of the EU Biodiversity Strategy for 2020, this report offers an overview of the vegetation and habitat mapping approaches and concepts and a comprehensive presentation of methods and projects carried out across Europe, including the historical development of habitat and vegetation mapping in individual countries.

The first vegetation maps in Europe were produced for scientific reasons. Vegetation mapping began in the mid Nineteenth century, with the oldest identified map being published in 1869 in the Netherlands. Most developments occurred in the Twentieth century and the development of vegetation mapping has been closely linked to the development of phytosociology (the study of plant communities). The earliest maps are often at small scales and covering entire countries or larger regions. They tended to be physiognomic, showing the types of formation present defined by the dominant species, e.g. coniferous forests or grasslands.

More recently, maps have been produced as an aid to implementing policies on land use planning and, in particular, nature conservation. Maps based on phytosociological concepts are widespread and take several forms. They can show either actual vegetation or potential natural vegetation (PNV). PNV is a concept introduced by the German phytosociologist Reinhold Tüxen in 1956 and can be defined as 'the vegetation that would finally develop (terminal community) if all human influences on the site and its immediate surroundings were to stop at once and if the terminal stage were to be reached at once'. Although often criticised, the concept has been very useful for many purposes and continues to be used.

Recent landmarks include maps from Spain, the Czech Republic and Italy, details of which are used as case studies throughout this report. Another major achievement has been the completion of a map of the PNV of Europe, published in 2000 at a scale of 1:2500 000 by a multinational team initially led by Robert Neuhäusl and then by Udo Bohn. This map, which uses some 700 mapping units, is accompanied by a detailed legend giving information about each unit.

Different classification schemes for vegetation and habitats are used for mapping. This report highlights the role of the European Vegetation Survey (EVS) in developing common standards across Europe for classifying vegetation and handling vegetation data. EVS is a working group of the International Association for Vegetation Science (IVAS). A first overview of European vegetation was published by the EVS in 2002. At the time of the present publication, a revised edition, this time with a complete synonymy, has been submitted to a journal for publication.

In this report the development of the concept of 'habitat' is discussed; from early definitions which today would be referred to as 'biomes', to the use by the EU Habitats Directive where habitats are defined as 'terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural'. The first comprehensive European habitats classification was the Corine biotopes, published in 1991. The Palaearctic classification, which was published in 1996, extended the geographical coverage. Both have been superseded by the EEA's EUNIS habitat classification, which gives criteria to identify each of the habitats in the upper levels of the classification. An important development has been the use of crosswalks to link various classifications, in particular to link plant communities to habitat types and to help link national to European classifications. The use of such crosswalks helps classifications such as EUNIS become a common language for habitats. This is demonstrated by its use under the EU INSPIRE Directive, which aims to enable the sharing of environmental spatial information among public sector organisations and better facilitate public access to spatial information across Europe.

Remote sensing has become increasingly important in vegetation mapping. Early applications pertained to aerial photography, but more recently satellite imagery with a variety of sensors is in use. Some mapping projects apply remote sensing to segment the landscape into homogenous polygons to aid field surveyors, while others produce maps directly from imagery by combining imagery with other spatial data sets. The latter approach is still experimental, but the technology is improving. Using a mixture of remote sensing and field methods seems to deliver the best results. This requires ecologists and remote sensing experts to collaborate closely.

The survey undertaken by the *Service du Patrimoine naturel* (SPN) of the French Muséum national d'Histoire naturelle (MNHN) and the European Topic Centre on Biological Diversity (ETC/BD) of the European Environment Agency (EEA) included a comprehensive bibliographical review which identified 163 mapping projects. From this, 65 were considered to be of interest for detailed analysis as they mapped large areas (defined as > 5 000 km² or > 50 % of national territory) and used a phytosociological approach or a typology which could be related (e.g. the Czech mapping project uses its own biotope classification but equivalent phytosociological units are given for each biotope class). These criteria were adopted in order to identify the projects of high importance for the French national habitat mapping CarHAB project.

A questionnaire, partly prefilled with information from the literature search, was sent to experts in 40 countries. The recipients were principally vegetation scientists and project managers working for nature conservation agencies, identified through different networks. These questionnaires were complemented by a series of interviews chosen to focus on projects of particular interest. The information gathered was stored in a database and validated using the EEA's Eionet by consulting the network of experts in national organisations for biodiversity and forests (National Reference Centres (NRCs)).

Of the 306 bibliographic references identified, 49 % were books, 37 % papers in scientific journals with the remaining 14 % in conference proceedings and grey literature. The majority of projects were national (66 %); only 3 % were transnational and 25 % regional. Efforts to ensure interoperability and compatibility between maps from different regions of the same country have been of varying strength, as seen in Germany and Spain. There are also projects of mapping the habitats within protected areas of a country, sometimes accounting for a large proportion of the national territory, for example in Bulgaria and Greece.

Only 20 % of projects mapped all habitats, the majority (52 %) only mapped natural and semi-natural habitats and 21 % only mapped habitats of natural heritage value (e.g. the habitats listed on Annex I of the Habitats Directive). Thematic mapping (e.g. grasslands or forests) is a common type of mapping but only formed 7 % of the projects covered by our survey as they tend to have low thematic resolution or cover small areas. The duration of mapping projects varies, but most (42 %) run for less than 5 years. Projects tend to be of longer duration in larger countries. Our results suggest that projects which allow insufficient time are likely to have problems with the quality of data obtained, while longer projects may have problems in being completed. Case studies from selected projects are included as examples of good practice.

It is clear that remote sensing techniques have become more widely used in recent years and this trend is likely to continue, however more than half of all the projects studied used field survey techniques. Several projects have pioneered the use of field computers. This helps the field surveyor in data capture and eliminates the need to transcribe field notes, potentially removing a source of error.

The use of habitat and vegetation maps to help implement the Habitats Directive is clearly of high significance. The map of the biogeographical regions used for the establishment of both the Natura 2000 and the Emerald network is based on PNV maps while in many countries site selection was based on existing or specially commissioned maps. Habitat maps are important for reporting under Article 17 of the Habitats Directive where distribution maps of the Annex I habitat types are required, together with estimates of their total area and trends. Similar information is also required for compiling Red Lists of habitats, typically at the national level and currently under development at the European level. The European Red List of habitats will contribute to an IUCN led initiative for the Red List of the world's ecosystems. Habitat maps are expected to play an important role in mapping and assessing ecosystem services as ecosystems can be regarded as groupings of habitat types.

Habitat maps are also very useful input to processes of spatial planning, including environmental impact assessments (EIAs) and assessments required under Article 6 of the Habitats Directive to protect the Natura 2000 network. They have been used when designing ecological networks from regional to continental scales, as with the Pan-European Ecological Network (PEEN), and will be important in implementing the European Commission's Green Infrastructure Strategy.

1 Introduction: background and aims

Habitats and vegetation

Habitats can be defined in several ways (see, for instance, Bunce et al., 2012), but the term usually refers to a combination of species and physical factors (e.g. soil type and climate) which occur together. The definition from the EEA's European Nature Information System (EUNIS) habitats classification (see Section 3.2.1) is commonly used:

'A place where plants or animals normally live, characterised primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality, etc.) and secondarily by the species of plants and animals that live there' (Davies, Moss and Hill, 2004).

Vegetation is formed by plant communities, usually defined by their floristic composition. These may be considered as a proxy for habitats for terrestrial systems; plant communities (especially in natural and semi-natural environments) are largely determined by physical environment, although they are often modified by management.

1.1 Habitat mapping and European biodiversity policies

Vegetation and habitat mapping have a long history in Europe. Earlier maps focused on vegetation mapping were usually produced for scientific purposes, and to increase our knowledge of the natural world. More recently, habitat maps have been used and increasingly produced to address policy-related issues.

Adopting the European Union (EU) Habitats Directive (92/43/EEC) has — directly or indirectly — been responsible for many of the mapping projects described in this report; it requires EU Member States to identify and designate sites for a selection of habitats (as listed in Annex I of the directive) to be included in the Natura 2000 network. The same directive requires EU Member States to report on the conservation status of these habitats at six-yearly intervals; this calls for solid knowledge of the geographical distribution of these habitats. The designation of Emerald sites (the counterpart to Natura 2000 for non-EU countries), underpinned by Resolution No 3 (1996) of the Council of Europe's Bern Convention on the creation of the Pan-European Ecological Network (PEEN), also requires knowledge of the distribution and extent of habitats.

More recently, the EU's Biodiversity Strategy to 2020 ([1]) included three targets calling for knowledge on habitats: Target 1, to fully implement the Birds (Directive 2009/147/EC) and Habitats Directives; Target 2, to maintain and restore ecosystems and their services; and Target 3, to increase the contribution of agriculture and forestry to maintaining and enhancing biodiversity.

A supporting action to Target 2 on the maintenance and restoration of ecosystems is Action 5, which calls for EU Member States to map and assess the state of ecosystems ([2]). For this action, ecosystems are defined as groups of related habitats, meaning that reliable information on distribution will be required for a wider range of habitats than for those listed in Annex I of the Habitats Directive and beyond protected areas.

Similarly, Action 6 of the same target on the promotion of the Green Infrastructure Strategy, launched in May 2013 by the European Commission,

([1]) See http://www.biodiversity.europa.eu\policy.
([2]) 'Member States, with the assistance of the Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020' (European Commission, 2011).

requires habitat information in order to assess the spatial structure of natural and semi-natural areas. This type of approach has been applied in the past by initiatives looking to develop ecological networks, at a variety of scales, in response to national or European policies. One such example is the Pan-European Ecological Network (PEEN), developed under the Council of Europe's pan-European biological and landscape diversity strategy (Jongman et al., 2011).

1.2 Aims and structure of the report

This technical report aims to collect information on initiatives taken by European countries in mapping terrestrial vegetation and habitats. The Service du Patrimoine Naturel (SPN) of the French Muséum national d'Histoire naturelle (MNHN) and the European Topic Centre on Biological Diversity (ETC/BD) collected the material for this analysis in a systematic inventory of habitat and vegetation mapping projects, using a comprehensive bibliographical review (317 scientific references) and a questionnaire sent to targeted experts from 40 European countries (see Annex 1). This review of experience across Europe was initiated within the framework of the French Cartographie des Habitats (CarHAB) programme (see Box 1.1), and should provide a useful reference work for those embarking on national or regional habitat-mapping projects (Ichter et al., in press). The information contained in the inventory has been validated by national authorities through a European Environmental Information and Observation Network (Eionet) consultation process organised by the EEA.

The origins, concepts and applications of vegetation mapping and the vegetation maps of Europe are described in Chapter 2. Chapter 3 presents the different classification systems, and endeavours to harmonise the concepts at European scale. Lessons learned from the use of remote sensing tools and habitat modelling are also presented, together with key references for further reading. Chapter 4 sets out the methodology and results of the questionnaire, followed by an analysis of the findings from selected projects (65 of the 163 inventoried). Chapter 5 presents a detailed analysis of mapping methodologies identified within the survey. Examples of uses and applications of habitat mapping, many of them in relation to EU policies, are presented in Chapter 6. Chapter 7 provides a historical perspective of vegetation and habitat mapping in different European countries.

The list of the 65 projects used in the survey appears in Annex 2. Annex 3 includes descriptive fact sheets for a few projects considered to hold special interest, and to serve as references when launching other

Box 1.1 CarHAB, a national habitat-mapping programme of France

Vegetation mapping in France started in the 1930s, and it is still a very active field, with more than 1 800 maps inventoried to date (see Section 7.3). However, comprehensive knowledge on the distribution of natural and semi-natural habitats at large scale (e.g. 1:25 000) for the entire country is missing. In 2011, the French government launched an ambitious project to map the terrestrial habitats of France — the CarHAB project. Such information is crucial to fulfilling its commitment to report on the conservation status of habitat and species of Community interest.

CarHAB represents a flagship programme for the French national biodiversity strategy. The objective is to produce a vegetation map of France at a scale of 1:25 000 by 2025, showing both actual and potential vegetation. The latest remote sensing and modelling technologies will be used to produce base layers prior to intensive field mapping. The outputs will be used as a strategic spatial planning tool to analyse green infrastructures, produce a national Red List of habitats and improve the national network of protected areas.

Because the project is so important, the French ministry responsible for the environment considered it essential to learn from the experience of similar projects elsewhere in Europe. Thus a systematic inventory of habitat and vegetation mapping was initiated by the MNHN and ETC/BD, in order to identify the most important programmes at European level. This review should be useful, not only for the French CarHAB programme but also for any large-area habitat-mapping project (Ichter et al., in press).

habitat mapping projects. Annex 4 provides an overview of the most commonly used approaches for mapping and modelling species and habitats distributions.

1.3 Key references

European Commission, 2011, *Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020*. COM(2011) 244, Bruxelles, European Commission.

Ichter J., Savio L. & Poncet L.,2012, *Synthèse des expériences européennes de cartographie de la végétation (Programme CarHAB)*, SPN MNHN, MEDDE, Paris.

Jongman, R. H. G., Bouwma, I. M., Griffioen, A., Jones-Walters, L. & Van Doorn, A. M., 2011, The Pan European Ecological Network (PEEN), *Landscape Ecology*, 26, 311–326.

2 Origins and concepts of vegetation mapping

Chapter 2 summary

This chapter introduces the history of vegetation mapping in Europe, the types of map produced and the concepts used.

In much of Europe, vegetation has been studied and classified predominantly using the methods of phytosociology (Dengler, Chytrý and Ewald, 2008). The basic unit of vegetation in this approach is the association; these are grouped into the higher units of alliance, order and class, with formal conventions for naming the units based on the scientific names of associated plants, as shown in Chapter 3, Table 3.1.

The chapter concludes with an overview of vegetation maps of Europe.

2.1 History of vegetation mapping

Vegetation mapping began in the mid 19th century, but developed rapidly during the 1900s. Its inception was preceded by a lengthy formative period covering various floristic, phytogeographical and vegetation studies, with the development of theories, which in turn led to the production of true cartographic documents. The development of geobotanical mapping was boosted by several international meetings, including those held in Stolzenau in 1959 (Tüxen, 1963), Toulouse in 1961 (Gaussen, 1961), St Petersburg in 1975 (Sochava and Isachenko, 1976), Klagenfurt in 1979 (Ozenda, 1980–1982), Grenoble in 1980 (Ozenda, 1981), Warsaw in 1990 (Faliński, 1991), Grenoble again in 1996 (Michalet and Pautou, 1998) and in České Budějovice in 1997 (Bredenkamp et al., 1998).

Journals dedicated to cartography were also published: examples are the *Bulletin du Service de la Carte Phytogéographique,* edited by L. Emberger (Montpellier), which was started in 1956 (now discontinued); the *Documents pour la Carte de la végétation des Alpes,* then the *Documents de Cartographie Écologique* (1963–1987) edited by P. Ozenda (Grenoble); *Geobotaniceskoe Kartografirovanie (Geobotanical Mapping)* (from 1963) edited by V. B. Sochava and E. M. Lavrenko (Saint Petersburg); and the *Supplementum Cartographiae Geobotanicae* (1988– ...) edited by J. B. Faliński (Białowieza-Warsaw).

Numerous specialised publications on vegetation mapping, illustrating both theoretical and practical aspects, were also produced (e.g. the work of Sochava, 1962; Küchler, 1967; Ozenda, 1986; Küchler and Zonneveld, 1988; Faliński, 1990–1991; Alexander and Millington, 2000; and Pedrotti, 2013). Some geobotanical publications also contained chapters on cartography (e.g. the work of Braun-Blanquet, 1928, 1951 and 1964;, Ozenda, 1964 and 1982; Borza and Boşcaiu, 1965; Puscaru-Soroceanu; Ivan & Doniţă, 1975; Ivan, 1979; Dierschke, 1994; Cristea et al., 2004; and others). A quite readable and less specialised summary of vegetation mapping, including its earlier history, was published by de Laubenfels (1975).

Throughout this period, the production of vegetation maps increased and improved, in both form and content, culminating in 2000 in the publication of the *Map of the Natural Vegetation of Europe*, directed by Udo Bohn (Bohn et al., 2000–2003) (see Section 2.3).

2.2 Concepts used in phytosociology

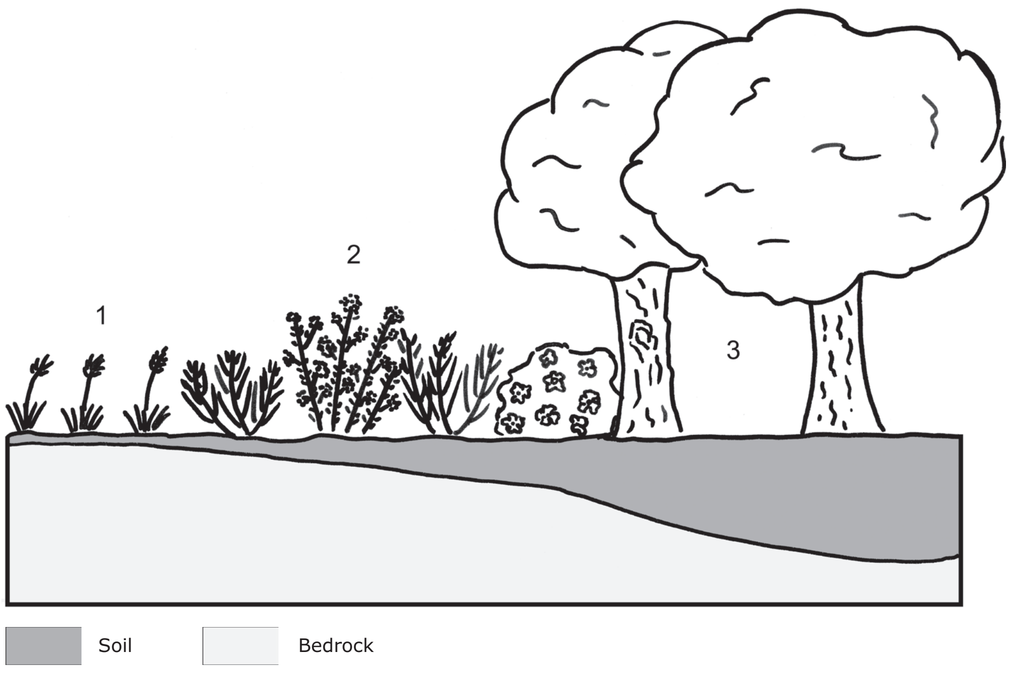
The most detailed and comprehensive classifications of vegetation types across Europe are provided by phytosociology, the discipline that studies patterns of co-occurring plant species. Phytosociology is based on the concept of association defined by Braun-Blanquet (1928) as a **vegetal grouping, more or less stable, and in equilibrium with the environment, characterised by a particular floristic composition, in which some exclusive or almost exclusive elements (characteristic species) reveal with their presence a particular and autonomous ecology**. To characterise plant associations, vegetation scientists record the plant species composition and cover on small-scale plots called *relevés* for 'bottom-up' fine-grained analyses (see Section 3.1.3). Associations are classified in a hierarchical system (see Section 3.1.1). The evolution of the concept of association is discussed by Biondi (2011).

A vegetation series is a list of the associations that could occur on a given area of land which is ecologically homogeneous with the same physical conditions (i.e. meso-climate, soil type, geomorphology) depending on management, extreme events (e.g. storm damage) and processes of vegetational succession (see Figure 2.1). Such successional series are sometimes referred to as chronosequences. Series are named after their most mature stage, usually the potential natural vegetation (PNV). Within the same meso-climate and under mesic soil conditions, the PNV corresponds to a single zonal vegetation (i.e. climatophilous series). In the case of azonal soils, edaphic factors induce different vegetation series within the same meso-climate (i.e. edaphophilous series). Finally, under extreme ecological conditions (e.g. sea cliffs, mobile screes and sand dunes) vegetational succession may be blocked and never reach the regional forest climax, resulting in curtaseries (a series limited to two or three associations) or permaseries (a series with only one association).

At the landscape level, a geoseries is the system of multiple series along an environmental gradient; often geoseries form repetitive patterns within a biogeographical unit. Figure 2.2 shows an example of a pre-Apennines plant landscape in central Italy.

The terminology used for dynamic and landscape approaches to phytosociology may be complex, and part of the literature is unavailable in English (see Rivas-Martinez, 2005; Lazare, 2009; and Biondi, 2011). For further reading, Kent (2012) provides an overview of phytosociology, while Géhu (2006) gives definitions of the concepts and terminology employed.

Figure 2.1 Example of a *Quercus pubescens* vegetation series in Italy



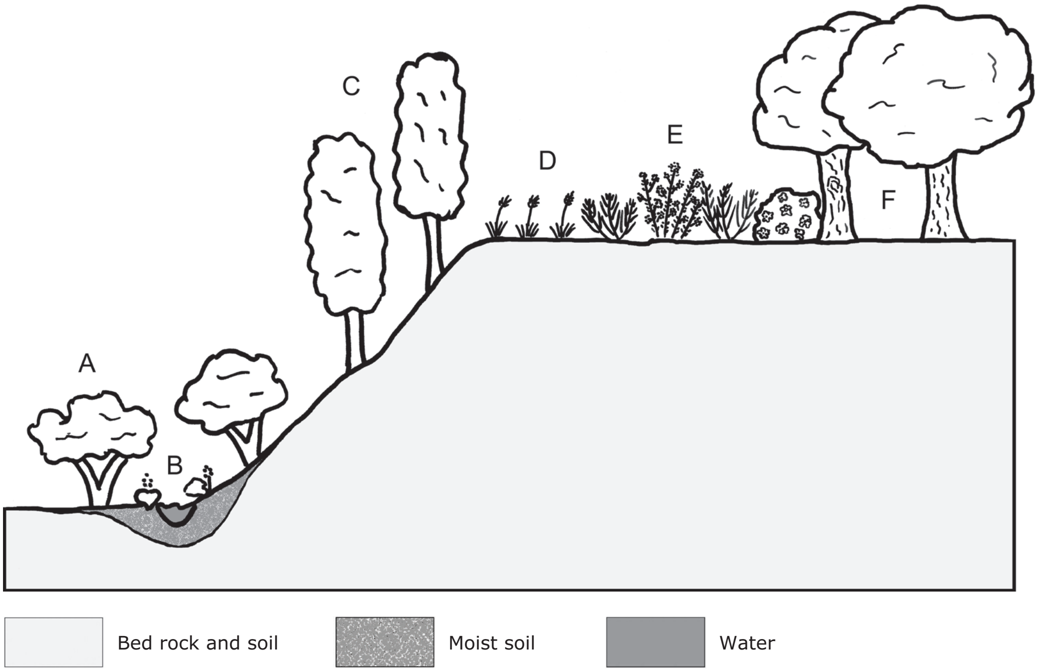
1: Grassland: group with *Clinopodium vulgare* and *Carex flacca*

2: Scrub: *Junipero communis-Pyracanthetum coccineae*

3: Forest (climax community): *Roso sempervirentis-Quercetum pubescentis*

Source: MNHN, based on Taffetan, 2009.

Figure 2.2 Example of a geoseries (plant landscape) in central Italy



A: *Aro italici-Alno glutinosae* sigmetum (series of permanently moist soils)
B: *Petasitetum hybridi* (riverside herb-dominated community, component of series A)
C: *Fraxino excelsioris-Acer obtusati ruscetosum hypoglossi* sigmetum (series of mesic soils of valley slopes)
D: Grouping of *Clinopodium vulgare* and *Carex flacca* (herb-dominated community, component of series F)
E: *Junipero communis-Pyracanthetum coccineae* (bush-dominated community, component of series F)
F: *Roso sempervirentis-Quercetum pubescentis* sigmetum (series of hilltop xeric soils)

Source: MNHN, based on Taffetani, 2009.

2.3 Main types of vegetation mapping

There are many types of vegetation maps, produced for diverse reasons. First, maps may show different aspects of vegetation, based on the floristic composition, structure, the ecology of plant communities (synecology), the dynamic stages and relations of plant communities (syndynamics) and the distribution of plant communities (synchorology). Each of these may be represented on a map. Secondly, maps may vary according to scale and definition of the vegetation units. Thirdly, a vegetation map depends on the theoretical conceptions of the different geobotanical schools, and thus on the interpretation and classification of vegetation resulting from these different approaches.

For these reasons among others, the cartographic typologies used by authors vary considerably: each is inspired by different criteria, emphasising some map characteristics more than others. In this section, we have only presented the main types of vegetation map. The question of vegetation classifications will be discussed in Section 3.1. The following listed types of vegetation map take into account the evolution of geobotanical thought since the middle of the 19th century, when the first vegetation maps were made. The maps regarded as 'fundamental' are listed first: they refer to the classification of vegetation and so represent the starting point for the production of other maps (e.g. those of dynamics or phytoecology).

Following Pedrotti (2013), the main types of vegetation map are as listed below.

1 Physiognomic maps

Physiognomic maps show the basic physical structure of the vegetation (forest, shrubland, grassland, etc.) based on the main growth forms (trees, shrubs, grasses, etc.) of the dominant or co-dominant species in the vegetation formation. The result is that the vegetation formations are defined rather generically, as deciduous forests, conifer forests, formations of evergreen sclerophylls, etc.

2 Phytosociological maps

Phytosociological maps show plant associations and vegetation series; it is possible to identify various levels of integration and thus of cartographic representation, according to the units to be mapped (see Figure 2.3). It is also possible to distinguish subtypes of phytosociological maps, in particular phytosociological maps of actual vegetation (i.e. maps of syntaxonomic units), integrated phytosociological maps (i.e. maps of vegetation series, also known as sigmeta or sigma associations), and phytosociological maps of potential vegetation (i.e. maps of climax syntaxonomical units). Maps of geoseries are no longer vegetation maps in the strict sense, but rather are maps of large complexes of vegetation (see Figure 2.2).

2a Phytosociological maps of actual vegetation
Phytosociological maps of actual (or 'real') vegetation represent the vegetation that is observed in the field at the moment of survey. Such maps show the spatial distribution of the vegetation units belonging to various syntaxa of the hierarchical phytosociological system, i.e. associations, sub-associations, variants, facies, alliances, orders and classes; these are classical phytosociological maps.

2b Integrated phytosociological maps
Integrated phytosociological maps, also known as synphytosociological maps, represent vegetation series (sometimes known as sigmeta, sigma associations or synassociations according to the concepts of Tüxen (1979), Rivas-Martínez (1985) and Géhu (1991)). In terms of cartography, it implies a complete representation of all the associations that compose the vegetation series. This analytic mapping is different from a summary mapping of the series (see 2c), limited to the representation of the association that is the head of the series or terminal community.

2c Phytosociological maps of potential vegetation
These maps refer to the PNV of Tüxen (1956), eventually redefined by Westhoff and van der Maarel (1973) as 'the vegetation that would finally develop (terminal community) if all human influences on the site and its immediate surroundings were to stop at once, and if the terminal stage were to be reached at once'. More recently, the classical definition of PNV has been amplified by Kowarik (1987), more emphasis has been placed on the influence of irreversible anthropogenic changes. Leuschner (1997) takes this further, and introduces the temporal dimension, thereby proposing the concept of potential vegetation adapted to a certain habitat. The concept of PNV has often been criticised; see Jackson (2013) and Mucina (2010) for recent overviews. Potential vegetation develops strictly in relation to successional changes that take place in the soil. Many biogeographical maps in Europe (see Map 5.2) and in other parts of the world (Miyawaki et al., 1989) are based on PNV or related concepts (e.g. reconstructed natural vegetation, vegetation series and geoseries).

2d Maps of vegetation dynamics
Maps of vegetation dynamics aim to show temporal variations in the vegetation, especially its dynamics, and can be drawn up with very diverse criteria according to the different schools. Maps of the dynamic tendencies of vegetation show the ecological processes related to the dynamics in the phytocoenoses at the time they were sampled in the field. One might say that they represent the dynamic state of the vegetation. These dynamic processes include fluctuation, primary succession, secondary succession, degeneration, regeneration and regression (Falinski, 1986).

3 Maps of vegetation conservation status

Concepts of naturalness, hemeroby and anthropisation of vegetation have been used, with much variation between authors. An example is the map of hemeroby of Austrian forests (Grabherr, 1998).

Figures 2.3 and 2.4 illustrate two approaches to producing phytosociological maps of potential vegetation:

- the classical inductive approach, corresponding to an integrated phytosociological map, is based on field-data collection, data classification and expert interpretation;
- more recent methods combining inductive and deductive approaches with landscape analyses prior to making field (syn-)phytosociological relevés.

Figure 2.3 The inductive approach to producing maps of vegetation series

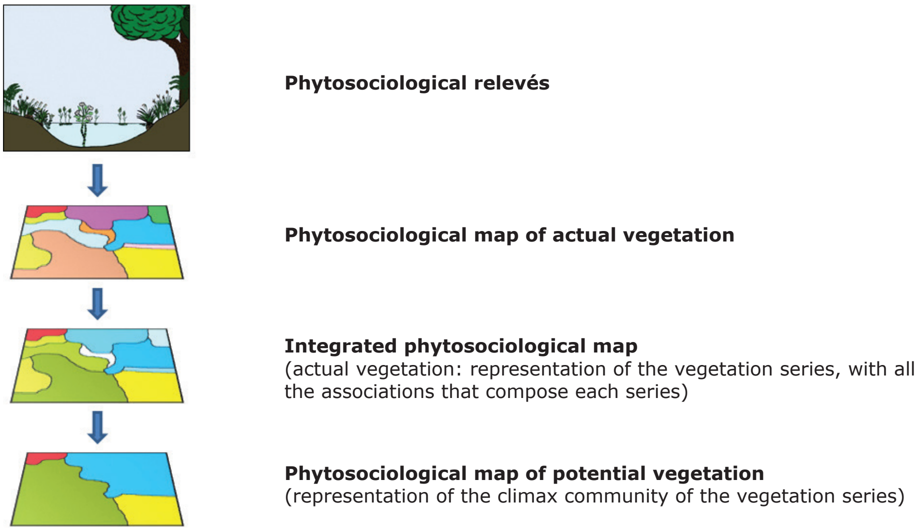
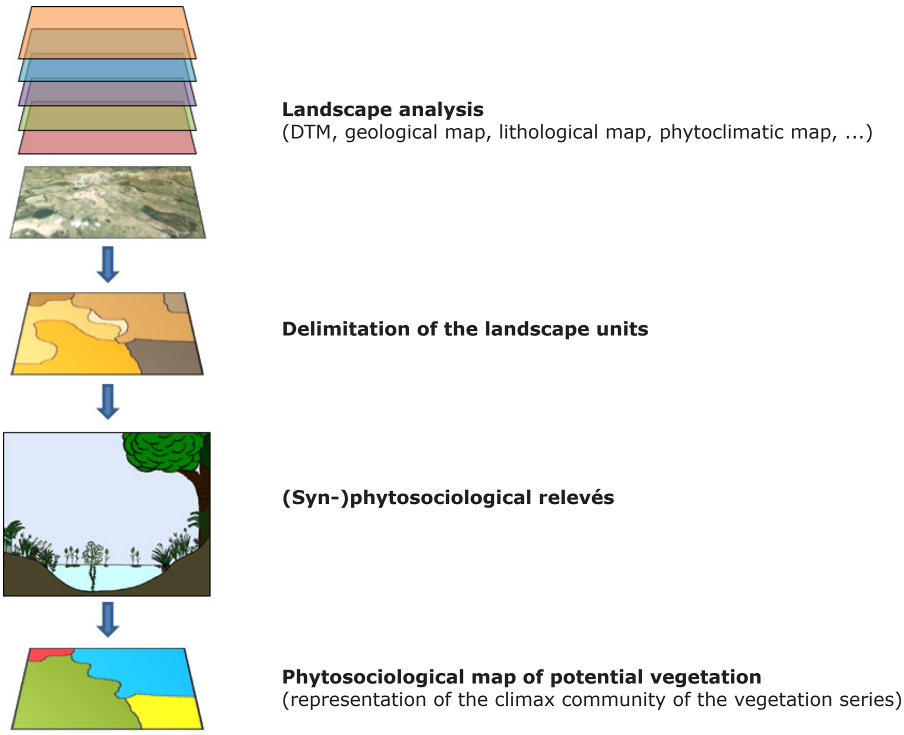


Figure 2.4 The combined inductive and deductive approach to producing maps of vegetation series



Source: MNHN, based on Rivas-Martínez, 1985; Géhu, 1991; Blasi et al., 2005; and Pedrotti, 2013.

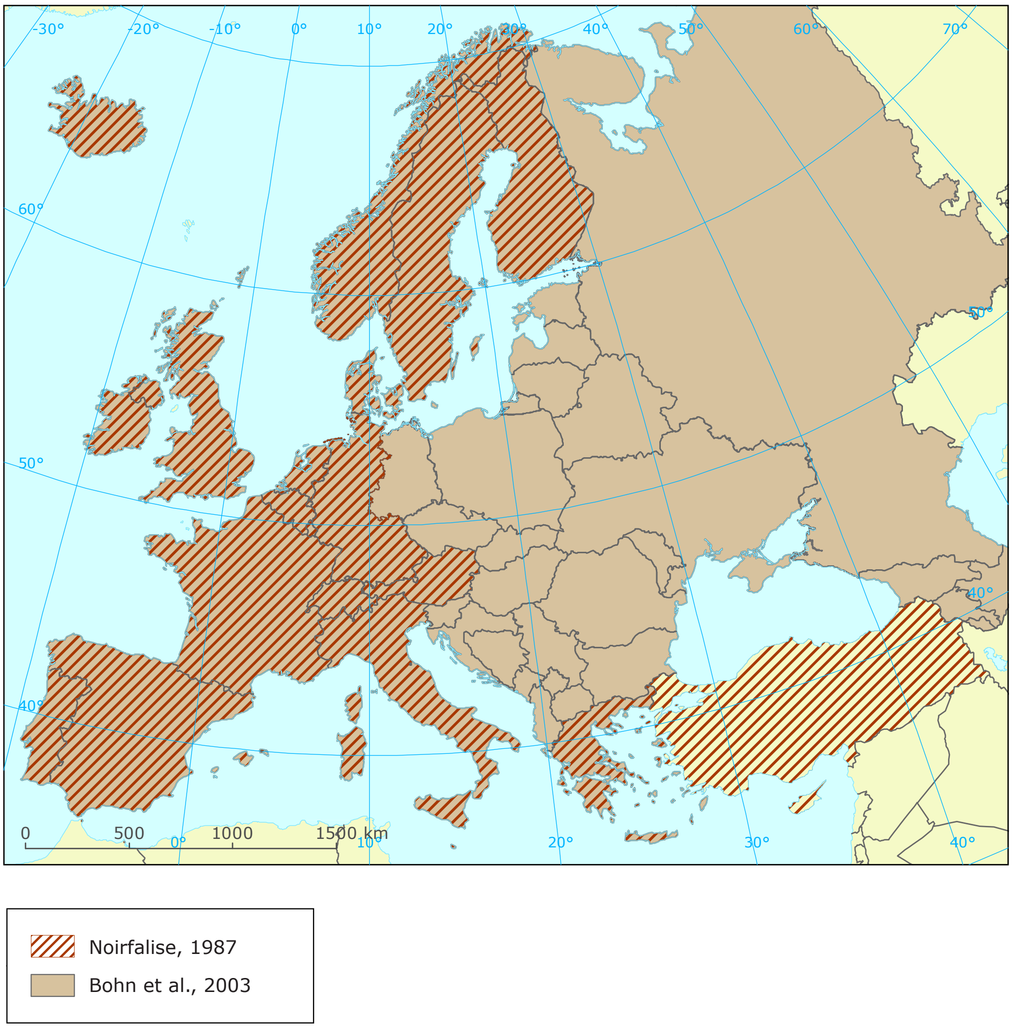
2.4 Vegetation maps of Europe

Two projects have produced medium-scale maps of European vegetation, both of PNV as defined by Tüxen (1956). The first to be published was produced for the Council of Europe (CoE) at a scale of 1:3 000 000 (Ozenda et al., 1979); this was later updated (Noirfalise, 1987). The CoE map aimed to depict the composition and distribution of natural edaphic and climax vegetation, actual or potential. This map was later digitised by the Corine biotopes project team.

The second project was pan-European, and involved more than 100 vegetation scientists from 31 European countries who cooperated in producing national maps in a standardised format, developing the overall legend and composing the explanatory text (Bohn et al., 2000–2003). The map is available in 9 sheets at a scale of 1:2 500 000, as an interactive CD-ROM or a GIS layer. The legend is built up of different hierarchical levels, comprising 19 major formations and 700 mapping units. Each mapping unit is documented: there is a general description, and information on the composition and structure of the main natural vegetation types, on distribution, ecology, land use, landscape pattern, actual plant communities and importance for nature conservation. The background data from each country include the local equivalents for each mapping unit and replacement vegetation under different management, often classified as the phytosociological syntaxa (Rodwell et al., 2013).

The coverage of the two maps is shown in Map 2.1: the Bohn et al. map covers a larger area, while only the CoE map covers Cyprus and Turkey.

Map 2.1 Coverage of the two maps of natural vegetation of Europe



Source: MNHN, ETC/BD.

The Circumpolar Arctic Vegetation Map (CAVM) project was an international effort organised by Conservation of Arctic Flora and Fauna (CAFF), a working group of the Arctic Council, to map the vegetation and associated characteristics of the circumpolar region, using a false colour infrared image created from Advanced Very High Resolution Radiometer (AVHRR) satellite data as the base map. A composite image was created by selecting pixels of maximum reflectance from 1993 and 1995 data. Mapping efforts in Canada, Greenland, Iceland, Norway, Russia and the United States used uniform methods to integrate information on bioclimatic zones, bedrock, surface geology, acidity of parent material, soils, hydrology, remotely sensed vegetation classification, Normalised Difference Vegetation Index (NDVI), previous vegetation studies, and the regional expertise of the mapping scientists (CAVM Team, 2003). Several maps were produced, including vegetation, bioclimatic zones and above-ground biomass.

The vegetation map uses a typology with five broad physiognomic categories: barrens, graminoid-dominated tundras, prostrate-shrub-dominated tundras, erect-shrub-dominated tundras, and wetlands. These are subdivided into 15 vegetation mapping units which are named according to dominant plant functional types, except in the mountains where complexes of vegetation are named according to the dominant bedrock (carbonate and non-carbonate mountain complexes).

More recently, CAFF has initiated an international project to produce a map of circumboreal vegetation with the aim of producing a global map of the circumboreal forest biome with a common legend (Talbot and Meades, 2011).

2.5 Key references

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3 Classification systems as tools for vegetation and habitat mapping

Chapter 3 summary

All maps of vegetation or habitats are based on a system of classification. For vegetation, this has usually been based on phytosociological synsystems, while classifications of habitats, being more recent, have been produced at national, regional and international levels (e.g. Czech biotopes, Nordic vegetation types and Corine biotopes). This chapter discusses the classification systems in use for mapping vegetation and habitats in different countries, and also the work towards harmonisation at European scale. It introduces the EUNIS habitat classification, proposed as a European standard under the EU INSPIRE Directive (Directive 2007/2/EC), and its crosswalks to and from other typologies. Finally, it presents the habitat typologies used for monitoring, statistical and distribution modelling approaches as developed by the BioHab and EBONE projects.

3.1 Classification systems based on characterisation of plant communities

3.1.1 The phytosociological approach to vegetation classification

The past century has produced an enormous body of phytosociological literature, with diverse proposals for classifying vegetation types throughout Europe and beyond, and a variety of 'schools': the Nordic (Uppsala) school and the Braun-Blanquet (Zurich-Montpellier) school are examples. As noted in Section 7.8, the Nordic school developed in a region with relatively low species diversity, where the concept of fidelity was more difficult to apply and where the importance of dominant species and life forms for the classification of communities was stressed (Becking, 1957; Lawesson, Diekmann and Eilertsen, 1997). In some ways, the approach developed by Poore and McVean in Scotland combined aspects of both approaches (Poore and McVean, 1957; McVean and Ratcliffe, 1962). The Braun-Blanquet approach, also known as 'Sigmatiste' (from Station Internationale de Géobotanique Méditerranéenne et Alpine, after the name of Braun-Blanquet's laboratory), has become dominant in recent years. Delimitation of vegetation types remains incomplete and contentious due to various theoretical constraints and methodological problems (see, for instance, Ewald, 2003; Mucina, 1997; and Pignatti, 1990).

As for species, formal rules exist for naming plant associations and organising them in higher syntaxonomic units (analogous to families, genera and species). The hierarchical system of syntaxa governed by the International Code of Nomenclature (Weber et al., 2000) is based on four principal ranks: association, alliance, order and class. Many authors also recognise sub-ranks (e.g. sub-associations or sub-alliances). Table 3.1 summarises this approach.

Table 3.1 The phytosociological approach to classifying vegetation

Level	Suffix	Example	Description
Class	*-etea*	*Carpino-Fagetea sylvaticae*	Mesic deciduous and mixed forests on eutrophic soils of temperate Europe, Anatolia, Caucasus and southern Siberia
Order	*-alia*	*Fagetalia sylvaticae*	Beech forests of nutrient-rich soils of Europe
Alliance	*-ion*	*Fagion sylvaticae*	Postglacial beech and mixed beech-fir forests of western central and northern Europe
Association	*-etum*	*Festuco altissimae-Abietetum albae*	Mixed beech-fir forests of the Vosges (France) with *Festuca altissima*

Source: From Mucina et al., in prep.; and Gegout et al., 2007.

3.1.2 *Initiatives for a harmonised European vegetation classification*

Although phytosociological approaches are widely used across Europe, they are not used by all countries, as Chapter 7 highlights.

In an attempt to achieve a respectable level of stability, the European Vegetation Survey (EVS) (see Box 3.1) developed the first overview of European vegetation units at the levels of alliances (928), orders (233) and classes (80). It was published with funding from the Dutch National Reference Centre for Agriculture, Nature and Fisheries as *The diversity of European vegetation* (Rodwell et al., 2002). This created a pragmatic framework of syntaxonomic units, each with a simple description relating all the alliances to the EUNIS habitat classification (see Box 3.3).

In the past few years, a very substantial revision of the phytosociological overview of alliances has been prepared by an EVS team under the leadership of L. Mucina. This new 'EuroVegChecklist' (Mucina et al., in prep.) is more up to date and thorough in terms of its syntaxonomy, more geographically comprehensive, and also includes an extensive synonymy. It comprises 1 028 alliances, 276 orders and 80 classes, including some entirely new units. However, as with the earlier Conspectus, it is possible to explore alternative names and status for syntaxa at any level using the extensive synonymy that lies behind the classification.

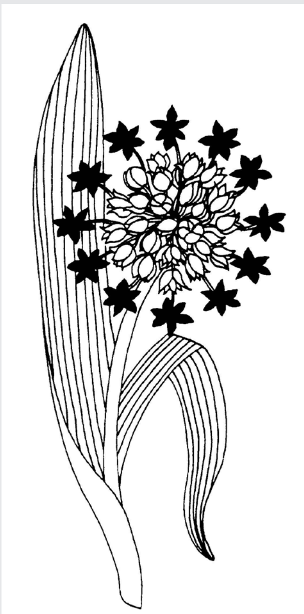
3.1.3 *Vegetation-plot databases: state of the art and perspectives*

Vegetation-plot samples (often known as *relevés*) provide the most numerous and widely dispersed in situ records of vegetation across Europe, and form the basis of the phytosociological classification of vegetation into associations, organised into the hierarchical systems. They have thus helped furnish inventories and maps of sites and accounts of the vegetation of countries and regions.

Various enquiries within and outside the EVS (Rodwell, 1995; Ewald, 2001; Schaminée et al., 2009) have provided an insight into the patterns of accumulation of vegetation plots across Europe over the past 90 years. The latest estimates (based on data from 32 countries) suggest that more than 4.3 million vegetation descriptions have been recorded. Most of these plots are in the countries of central and western Europe, particularly Germany, France and the Netherlands, but considerable numbers were also estimated for the Czech Republic, Spain, Italy, Austria, Poland and the United Kingdom (Schaminée et al., 2009).

Box 3.1 The European Vegetation Survey, a new spirit in European vegetation science

The EVS is a Working Group of the International Association for Vegetation Science (IAVS), uniting plant ecologists interested in vegetation survey and classification in Europe and beyond.



The purposes of the EVS are to:

- develop common data standards in the provision of phytosociological information;
- encourage national programmes of vegetation survey across Europe and beyond;
- develop software and an electronic network for vegetation data exchange;
- produce an overview of European vegetation;
- organise scientific meetings;
- encourage international research collaboration in vegetation survey;
- support publications on concepts, methods and results of vegetation survey.

The EVS was established in 1992 by leading European scientists involved in vegetation survey projects.

Further information about the EVS is available at http://euroveg.org.

Box 3.2 Case study: VegItaly

VegItaly (see http://www.vegitaly.it) is a long-term project coordinated by the Italian Society for Vegetation Science (SISV) and the Italian Botanical Society (SBI). It is registered in the GIVD (Dengler et al., 2011) with the ID: EU-IT-001 (see http://www.givd.info/ID/EU-IT-001) (Venanzoni et al., 2012). It allows the compilation of data collected by researchers using a variety of approaches. Following the definition of 'vegetation database' suggested by the GIVD (Schaminée et al., 2009; Dengler et al., 2011) and the Eco-informatics working group of the International Association of Vegetation Science, it provides certified support for scientific research.

VegItaly was conceived and developed as a subproject of the open-source project 'anArchive for Botanical Data' (see http://www.anarchive.it), a web geodatabase designed to manage floristic and vegetation data (Venanzoni et al., 2012). The initial project anArchive started in 2000. Initially it was mainly dedicated to managing herbaria and floristic data, and involved only the universities of Perugia, Camerino and Siena (Panfili et al., 2004). Later, the imperative to have an integrated system for floristic and vegetation data at national scale for studying and monitoring biodiversity resulted in the rapid development of the database system. Several structural and application improvements have been made to widen the scope for users and to facilitate the research (Gigante et al., 2012), and an increasing number of universities are getting on board (Landucci et al., 2012).

VegItaly is also one of the founding members of EVA (see http://euroveg.org/eva-database), a recent initiative of the EVS (Chytrý et al., 2012).

Main aims and advantages

The aims of the project are to:

- build a vegetation database at national level that contains historical and current data, both published and unpublished;
- provide standards for data collection and archiving, in line with national and international guidelines;
- create a robust support base for syntaxonomical, synecological and geobotanical researches, in particular large-scale vegetation classifications, statistical data analyses, and spatial and temporal analyses of floristic and vegetation data for monitoring environmental changes and ecosystems;
- facilitate data sharing and comparisons among European countries;
- create a web interface for accessing and disseminating data.

A national vegetation database is a fundamental instrument for improving research in vegetation science. Large databases enable the production of syntheses and studies across wide geographical areas, and open the doors to national and international cooperation among scientists.

Respecting standards in data collection and storage is an important factor for data sharing at national and international scale, and for the creation of common infrastructures and the easy application of common policies as provided by the INSPIRE Directive.

Organisation and technical details

VegItaly uses open-source software and applications. It has a web server for data upload, client applications for data storing and managing, and a web interface for visualising, exploring and retrieving data (Gigante et al., 2012; Landucci et al., 2012). Access and consultation of the database via the Internet are free for public data, while the retrieval and use of data are regulated by rules determined by individual data owners. The stored data can only be managed and used in accordance with the VegItaly rules, developed by the

Box 3.2 Case study: VegItaly (cont.)

Management Committee of VegItaly, approved by the SISV Governing Council and published on the VegItaly website (see http://www.vegitaly.it).

Current status and prospects

At present, VegItaly involves about 18 Italian universities and hosts 31 100 vegetation plots, including both published (74 %) and unpublished data (26 %). The most represented vegetation types are herbaceous (56 %), forest (35 %) and shrub (6 %) vegetation. The largest amount of data comes from central Italy. The main reason for this uneven geographic distribution is that universities from central Italy were the majority at the beginning (Landucci et al., 2012). Although the number of *relevés* has increased rapidly recently, the data presently stored in the database are still considered far from complete or representative of all the Italian vegetation types. However, the popularity of the database is on the rise, and more and more research institutions are joining the project. We expect a rapid increase in the number of users and stored *relevés* in the near future. Moreover, new functionalities and improvements will soon become available, e.g. with GIS and web cartographic presentation of the data, and export in a common format to facilitate data exchange with other database systems and national and international initiatives (Wiser et al., 2011; Martellos et al., 2011).

The development of compatible software tools, one of the EVS core work objectives, has greatly encouraged the development of national and regional vegetation databases. It has fostered the creation of a network facilitating data exchange and research collaborations and has assisted the emergence of supranational vegetation revisions and overviews over the last 20 years. The major software tool for database development has been TURBOVEG (Hennekens and Schaminée, 2001); now accepted as an international standard for data input, storage, management and retrieval, it has been installed in more than 30 countries in Europe and beyond (Schaminée and Hennekens, 1995). Complementary to TURBOVEG, the JUICE program (Tichý, 2002) has added a wide range of analytical tools for data sets that can include thousands of *relevés*.

Schaminée et al. (2009) showed that more than 1.8 million *relevés* had been already digitised, 75 % of which are found in centralised databases of countries or regions. Of all captured *relevés*, 59 % are available in the TURBOVEG format. Further key steps have now been taken by many EVS members to locate and capture additional plots, and to centralise data storage of such plots. The Global Index of Vegetation-Plot Databases (GIVD) platform (Dengler et al., 2011) was developed to provide a meta-resource of electronic databases whose hosts are willing in principle to share the captured data. Already, 83 European databases covering more than 1.6 million *relevés* have been registered. The GIVD platform also assisted in revealing gaps in the coverage and/or availability of the vegetation-plot data. Another recent initiative, the EVA, will yield a centralised database of phytosociological *relevés* to which data from the Czech Republic, Germany, Italy, the Netherlands Austria, Poland, Slovenia, Slovakia, the United Kingdom and some Nordic and Baltic regions have already been pledged (Chytrý et al., 2012). Each relevée in this archive will have a unique Global Unified Identifier (GUID), and version control will be used to date uploads.

3.2 Classification systems based on habitat and biotope concepts

Traditionally, maps have been produced showing vegetation, usually defined by species composition or physiognomy. Increasingly, especially since the EU Habitats Directive came into force in 1992, maps are being produced which show habitat types or biotopes.

Typologies based on phytosociological classification are strictly defined by plant communities, whereas habitat types or biotopes take into account geographic, abiotic and biotic features. According to the results of our survey (see Chapter 4), the term biotope mapping is used as a synonym for habitat mapping in central Europe.

The approach developed by the BioHab and EBONE projects, using plant life forms to produce General Habitat Classes (GHC) (see Section 3.2.2), is designed to be used with sampling techniques to give statistically valid data on the extent of habitats.

Box 3.3 Corine biotopes, Palaearctic and EUNIS habitat classifications

The Corine Biotopes classification was published in 1991 (Devillers, Devillers-Terschuren & Ledant, 1991) as part of the Corine Biotopes project which aimed to identify and describe the habitats of major importance for the conservation within the European Community (then comprising only 12 Member States). It is a hierarchical classification system intended to cover all habitat types but with a focus on natural and semi-natural habitats and a limited coverage of marine habitat types. Although it is clearly based on phytosociological classifications, it also includes other factors like geography, climate and soil, and covers several habitat types with no plant cover (e.g. glaciers and lava tubes). The original version of Annex I of the EU Habitats Directive as published in 1992 is a selection from the Corine biotopes classification (Evans, 2010).

The Corine biotopes classification was extended to cover all of Europe in the CoE funded Palaearctic Habitats Classification (Devillers Devillers-Terschuren 1996) with descriptions and links to syntaxa available in the associated PHYSIS database. Although the Palaearctic Habitats Classification extended the geographical coverage, treatment of marine habitats remained poor and no criteria to distinguish related habitat types were given.

In 1995, the EEA, through its European Topic Centre on Nature Conservation (the ETC/BD's predecessor), began work on the EUNIS habitat classification (Davies and Moss, 1999; Davies, Moss and Hill, 2004): the aim is a comprehensive hierarchical classification of the terrestrial, freshwater and marine habitats for the whole of Europe, associated islands and seas. Criteria in the form of keys are given for the first three levels of the classification (four for marine habitats) and crosswalks to other classifications have been developed, including both national and regional habitat classifications and syntaxa at the level of alliances (see Section 3.3). The EUNIS habitat classification has gained widespread respect among practitioners and environmental policymakers across Europe, and provides an important standardising tool for the EEA and its member countries.

The EU INSPIRE Directive, which aims to allow for the combination of spatial data and services from different sources across Europe in a consistent way, proposes that the EUNIS habitat classification be used as a common reference for habitats.

3.2.1 Habitat and biotope: concepts and definitions

Habitat is a widely used term, but it has many interpretations and is used inconsistently. There are various reasons for this, not least because habitat is used across diverse contexts with different meanings. It is used in nature policy for areas with a defined species composition (both fauna and flora) and associated physical factors (e.g. climate and soil type), as in the Corine biotope, EUNIS habitat and Palaearctic habitat classifications, and this is the meaning used by the EU Habitats Directive.

In ecology, however, the term habitat was traditionally defined as the spatial extent of a resource for a particular species. Habitat in the ecological sense is explicitly linked to a species or species group that share the same environmental and ecological requirements. Other terms such as biotope and ecosystem are also used in similar contexts in the literature but are rarely defined. The meaning of the term habitat in scientific use has evolved from the vague and broad to the narrow and precise, as shown by the following examples of definitions (Bunce et al., 2013).

A habitat is:

- a place or living space, where an organism lives;
- a place where a species normally lives, often described in terms of physical factors such as topography and soil moisture and by associated dominant forms, e.g. intertidal rock pools;
- an area comprising a set of resources, consumables and utilities for the maintenance of an organism. The resources occur in union and/or intersect, and links between resources outlets are established by individual movements of the organism.

These definitions are primarily theoretical and descriptive. The concept of habitat developed initially from when biomes were described by such classical biogeographers of the 19th century as Von Humboldt (Von Humboldt and Bonpland, 1807). Their maps showed the main biomes across the world (e.g. desert, tundra and tropical rainforest), and were based on a combination of observed vegetation and climate.

Early in the 20th century, Raunkiær (1904) formalised vegetation structure by using plant-life form spectra to define regions according to their actual vegetation rather than by also involving climate. In the early 20th century, the discipline of vegetation science developed as scientists recognised that plants formed recognisable assemblages — this led, in due course, to the science of phytosociology (Braun-Blanquet, 1932). This has been elaborated subsequently for vegetation mapping (Küchler and Zonneveld, 1988). Recently, Bunce et al. (2008) have adapted the principles developed in the Countryside Survey of Great Britain for mapping European habitats, and have provided rules for assignment of a given patch to a habitat class at a defined scale. Bunce et al. (2008) define habitat as 'an element of the land surface that can be consistently defined spatially in the field in order to define the principal environments in which organisms live'. Geijzendorffer and Roche (2013) have tested if this system can be used as variables for biodiversity indicators and ecosystem services. This is in line with the increasing use of the concept of ecosystem services, but as described by Fisher et al. (2009) in this context, it is usually applied at a range of different scales, including crop fields and habitats such as riparian zones.

In the Habitats Directive, natural habitats are defined as 'terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural'. The habitats for which sites must be designated are listed in Annex I of the Habitats Directive and described in the *Interpretation Manual of European Union Habitats* (European Commission, 2013). Although the *Interpretation Manual* is more detailed than the list of habitat names in the annex itself, there are many problems in trying to identify habitat types in the field, selecting sites, assessing the national lists of proposed sites and monitoring. Some of these problems arise from poorly defined, sometimes overlapping, habitat types, and others are due to errors within the Palaearctic classification or its associated PHYSIS database (Evans, 2006). This has led to differences in interpretation between countries and regions (see Section 3.3.2). Annex I of the EU Habitats Directive is a selection of habitats from several classifications and is not a classification.

Although the original version of Annex I as included in the 1992 edition of the Habitats Directive was based on the Corine biotopes classification, about 60 % of the Annex I habitats are clearly linked to one or more phytosociological syntaxa. Annex I has been adapted over time due to the enlargement of the EU from 12 to 28 Member States. With each expansion of the EU, additional habitats have been added and, where necessary, the description of existing habitats modified (Evans et al., 2013).

3.2.2 *Habitat characterisation for statistical and monitoring purposes*

The General Habitat Categories (GHC) were developed as part of the EU-funded BioHab and EBONE projects. Tested in Europe, and for non-European Mediterranean and desert environments, the approach has been applied successfully in field inventories and for linking remote sensing information with in situ data. As habitat is a key entry to other biodiversity stock and change variables, it is important to integrate approaches.

By using GHCs, it is possible to get a good correlation between remote sensing categories and in situ habitat data. In remote sensing, the spectral characterisation of different habitats is related to the spectral properties of the plant life forms and non-plant life forms. In addition to recognition in their own right, habitats also have the following practical advantages for monitoring:

- aerial photographs, especially infrared, can be used to estimate habitat extent and its change over time (e.g. Stahl et al., 2011);
- remote sensing data from satellites can be linked to in situ maps of habitats to larger units (e.g. Mücher, 2009; and Vanden Borre et al., 2011) (see Section 5.6);
- relationships can be made between habitats and species assemblage composition or particular taxa important to biodiversity, e.g. Petit and Usher (1998);
- habitat records can be linked to changes over time at the landscape level and to vegetation assemblages, as described by Haines-Young et al. (2007);
- protocols are now available that have been used to link extant habitat data across Europe for five national major monitoring programmes (Bunce et al., 2012), and others could also be developed for other surveys.

3.3 Crosswalks between typologies and interpretation issues

3.3.1 Crosswalks between typologies: uses and limits

Although there are many habitat classifications, it is usually possible to derive links that connect them, often presented as tables and known as crosswalks. Unfortunately the links are often from many to many rather than one to one. Table 3.2 shows part of a crosswalk from Annex I of the EU Habitats Directive to the EUNIS habitat classification. These relationships can be described and the EUNIS website ([3]) uses a series of symbols as described in Figure 3.1.

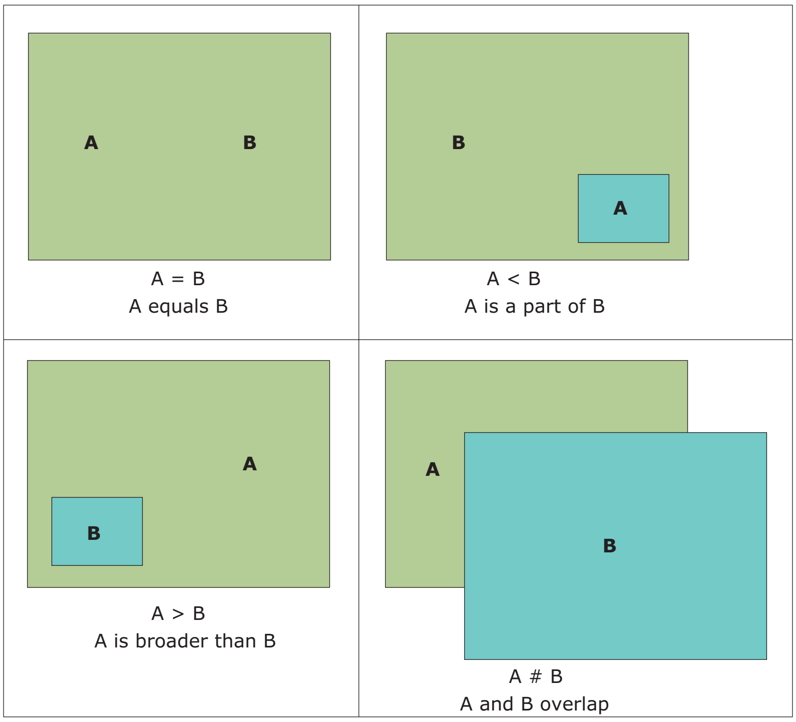
Crosswalks aid translation between different habitat classifications, but they should be used with care. In many cases, it is possible to give more definitive relationships if a crosswalk is for a region or country rather than for Europe. For example, the EUNIS habitat 'G3.4 *Pinus sylvestris* woodland south of the taiga' includes six Annex I habitats (and also forest types not covered by Annex I), but in Scotland it would only include '91C0 Caledonian forest'.

Table 3.2 Extract from a crosswalk between Annex I-EU Habitats Directive and the EUNIS habitat classification

Annex I habitat	Relationship (see Figure 3.1)	EUNIS habitat
9050 Fennoscandian herb-rich forests with *Picea abies*	<	G3.A *Picea* taiga woodland
	#	G3.A2 Fern western *Picea* taiga
	>	G3.A3Small-herb western *Picea* taiga
	>	G3.A4Tall-herb western *Picea* taiga
9070 Fennoscandian wooded pastures	#	X09 Pasture woods (with a tree layer overlying pasture)
9080 Fennoscandian deciduous swamp woods	<	G1.5 Broadleaved swamp woodland on acid peat
	#	G1.51 *Sphagnum Betula* woods
	#	G1.52 *Alnus* swamp woods on acid peat
9110 *Luzulo-Fagetum* beech forests	<	G1.6 *Fagus* woodland
	=	G1.61 Medio-European acidophilous *Fagus* forests
9120 Atlantic acidophilous beech forests with *Ilex* and sometimes also *Taxus* in the scrublayer (*Quercion robori-petraeae* or *Ilici-Fagenion*)	<	G1.6 *Fagus* woodland
	=	G1.62 Atlantic acidophilous *Fagus* forests
9130 *Asperulo-Fagetum* beech forests	<	G1.6 *Fagus* woodland
	=	G1.63 Medio-European neutrophile *Fagus* forests
9140 Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	<	G1.6 *Fagus* woodland
	=	G1.65 Medio-European subalpine *Fagus* woods

([3]) See http://eunis.eea.europa.eu/habitats.jsp.

Figure 3.1 Possible relationships between different habitat classifications, and symbols used in EUNIS website



Box 3.4 Crosswalks between the EVS and EUNIS

The development of the EUNIS habitat classification afforded a fresh opportunity to provide a sound scientific cross-reference between widely accepted European habitats and phytosociological definitions of vegetation types. With funding from the EEA-ETC/BD, an EVS team developed a crosswalk between phytosociological units to the level of the alliance and EUNIS habitats at Level 3. *The Scientific Background to the EUNIS Habitat Classification* (Rodwell et al., 1998) provides a complete overview of European vegetation types to the level of alliance, accompanied by brief verbal definitions of these units, and crosswalks from the EUNIS-3 habitats to the syntaxa and vice versa. The background files held by the EVS also provided a limited synonymy and bibliography for the phytosociological units. The syntaxa to the EUNIS-3 habitats crosswalk and an introduction to the background and application of the work were included in Rodwell et al. (2002), while the EUNIS habitats website ([4]) used the crosswalk to show which alliances were linked to the EUNIS classes.

With the production of the 'EuroVegChecklist' (Mucina et al., in prep.), the crosswalks between alliances and EUNIS Level 3 habitats are also under review by EEA-ETC/BD in collaboration with an EVS team. Once finalised, the crosswalks will be implemented in the desktop tool Syntaxonomic Biological System Europe, better known as SynBioSys Europe (Schaminée et al., 2007), an EVS initiative coordinated by Alterra in the Netherlands which integrates different biological levels: species, community and landscape (see Box 4.7) and linked to the EUNIS website.

([4]) See http://eunis.eea.europa.eu/habitats.jsp.

3.3.2 *Interpretation issues at national and European scales*

Experience shows that there are differences in how habitats or plant communities are interpreted at a variety of scales. For example, such differences can occur between different surveyors working in the field who may allocate different habitats or plant communities to a given polygon; even if they have a similar understanding of the habitats in the area, they may place the boundaries between habitats in different places (see, for instance, Cherrill and McClean, 1999a and b; and Hearn et al., 2011). Differences also result from local interpretations of documents prepared for use at national or European scale and possibly in another language. Problems have often been highlighted with the interpretation of the descriptions of

Box 3.5 Case study: management of correspondences and interpretation issues between typologies in France

In France, the *Cahiers d'habitats* series (Bensettiti et al., 2001–2005) form the basis for the interpretation of habitats of Community interest with the SPN (a section of the MNHN), ensuring that correspondences between phytosociological units and habitats of Community interest take into account changes in our understanding, including revisions to the French synsystem.

Revision of the French synsystem can result in a syntaxon being placed in a different, higher level, unit — resulting in changes in how the syntaxon is related to a habitat of Community interest. In this instance, three options are available:

- case 1: the syntaxon remains attached to the same habitat of Community interest;
- case 2: the syntaxon must be attached to another Annex I habitat;
- case 3: the syntaxon is no longer attached to any Annex I habitat.

Examples

Case 1
In the *Cahiers d'habitats*, the grassland association *Teucrio scordioidis — Agrostietum stoloniferae* was placed in the alliance *Molinio arundinaceae — Holoschoenion vulgaris*, and attached to the habitat '2190 Humid dune slacks'. Following a revision of the French synsystem, this association has been transferred into the alliance *Trifolio fragiferi — Cynodontion dactylonis*, which had no correspondence with the habitat 2190. However, the Annex I habitat is not linked to any particular phytosociological unit (such as the *Molinio — Holoschoenion*), but corresponds to all communities located in humid dune slacks, whatever their place in the synsystem may be. Thus the correspondence between *Teucrio –Agrostietum* and habitat 2190 has been maintained.

Case 2
In the *Cahiers d'habitats*, the forest association *Luzulo sylvaticae — Fagetum sylvaticae* was placed in the suballiance *Ilici aquifolii — Fagenion sylvaticae* and attached to the habitat '9120 Atlantic acidophilous beech forests with *Ilex* and sometimes also *Taxus* in the shrub layer (*Quercion robori — petraeae* or *Ilici — Fagenion*)'. Recent works on the phytosociological classifications of forests have concluded that this acidophilous association should be transferred to the suballiance *Scillo lilio-hyacinthi — Fagenion sylvaticae* (alliance *Fagion sylvaticae*). So far, the vegetation belonging to this suballiance has not been considered to be attached to any habitats of Community interest by the French authorities. Thus, *Luzulo sylvaticae — Fagetum sylvaticae* is no longer considered to be attached to an Annex I habitat by French scientists.

Establishing these correspondences is a complex task; it is essential that fieldworkers understand them and follow the same interpretation of habitats. Otherwise, the same vegetation observed in the field may be assigned to different habitats by different operators. This work is supported by the French Ministry of Ecology and conducted in close collaboration with a wide range of experts, in particular members of the Fédération des Conservatoires botaniques nationaux and of the Société française de phytosociologie.

the habitats of Annex I of the Habitats Directive — such discrepancies are found both between countries and between regions of a single country. For example, although the *Interpretation Manual of European Union Habitats* clearly notes that habitat type '9190 — Old acidophilous oak woods with *Quercus robur* on sandy plains' includes four associations (*Querco-Betuletum, Molino-Quercetum, Trientalo-Quercetum roboris and Peucedano-Quercetum roboris*), official guidance in Poland (Herbich, 2004) only includes the *Querco-Betuletum*, although *Molinio-Quercetum* is present in Poland. Further examples are given in Bagella et al. (2007), Biondi, Casavecchia and Pesaresi (2010), and Evans (2006 and 2010).

3.4 Habitat detection and characterisation using remote sensing

3.4.1 Remote sensing: detection and classification of habitat based on physiognomic types

Vegetation mapping over large areas and at larger scales can benefit greatly from remote sensing data. Historically, Earth observation data were first acquired from aircraft: the main developments, before or during the Second World War, occurred with the advent of orthophotos, colour and colour infrared films. The first civilian Earth observation satellite was Landsat-1. Launched in 1972, it acquired a 4-band (blue, green, red and infrared) medium-resolution (around 80 m) imagery over large scenes (typically 180 x180 km) worldwide (Strahler et al., 1978). Today, satellites carry optical sensors offering high (HR — from 5 m to 20 m) or very high (VHR — around 60 cm) spatial resolutions in the visible spectrum, and coarser resolutions for spectral bands in the medium or thermal infrared, or active sensors such as radars. For airborne data, the choice is even wider, from optical very-high spatial resolution (around 10 cm) or optical very-high spectral resolution (hyperspectral), to radar and Laser Imaging Detection and Ranging (LiDAR) sensors. Since different sensors have varying spectral and spatial and temporal characteristics, the selection of appropriate sensors is very important for mapping vegetation cover.

Sensor characteristics

In the visible spectrum (400–700 nm), sensors are sensitive to the foliar pigments of the leaves, and thus to chlorophyll content, or otherwise to leaf biomass (leaf area index (LAI), leaf area per ground m^2). At longer wavelengths of the solar spectrum, other parameters are more active: canopy leaf structure (i.e. dry matter) in the near infrared (NIR) (700–1 500 nm) and vegetation water content in the medium infrared (MIR) (1 500–3 500 nm). Several indices have been developed to better identify and characterise vegetation. The best known, the NDVI, uses the red and the NIR bands (Rouse et al., 1973).

Radar and LiDAR are active systems that emit radiation at a certain wavelength and analyse the return signal after it has interacted with the vegetation and the ground. Satellite and airborne imaging radar systems operate with different wavelengths. Shorter wavelengths (X band (3 cm) and C band (6 cm)) interact with leaves through their water content, while longer wavelengths (L band (25 cm) and P band (60 cm)) interact with trunks and larger branches of forest trees, giving information on forest biomass (Le Toan et al., 1992). Radar, in particular synthetic aperture radar (SAR), has the advantage of being insensitive to cloud cover, although it does require specific processing (polarisation and speckle noise). Airborne imaging LiDAR systems use monochromatic infrared pulses, usually in the infrared wavelength (1 064 nm and 1 550 nm), that penetrate the vegetation to the ground. Advanced LiDARs emit pulses at very high rates (up to 300 kHz) and scan the return signals, detecting the first return (top of canopy), the last return (ground), and intermediates to build 3D point clouds (Puech et al., 2012). The processing of these point clouds allows the production of 3D vegetation models as well as detailed digital terrain maps (DTMs). Hyperspectral systems operate in the solar spectrum (visible to MIR) and use numerous (from 15 to several hundreds), very narrow (5 to 10 nm, compared with 70 to 100 nm for other optical systems) bands. The narrowness of the bands allows the possibility that a certain chemical constituent of the land cover or vegetation will influence a certain wavelength, and explains why hyperspectral data have been tested for detecting monospecific stands of invasive species (Underwood et al., 2003).

Spatial characteristics

The choice of remote sensing data sets will determine the amount of information that is actually available to map complex, fine-scale and structurally and floristically variable habitats to sufficient degrees of accuracy, and to monitor changes over time (Nagendra, 2012). In addition to the spectral resolution, the issue of spatial resolution is among the most critical in the selection of data sets for habitat mapping. The adequacy/quality of spatial data sets and data sources is an important consideration. The choice of the spatial resolution depends on the spatial scale, the distribution and the heterogeneity of the species and habitats being monitored, the factors that control species distributions, and the availability of ancillary data sets related to, for example, soils, drainage networks, geology, topography, population and/or management regimes, that provide additional insights required for interpretation of remote sensing data sets (Nagendra, 2001). Ideally, the size of the pixel should be matched so that it is one quarter to one third of the size of the smallest patches of habitat, species assemblage or individual plant/tree being mapped. Some studies exploring the use of medium-resolution (few tens of metres) and high-resolution (a few metres) satellite images for assessing plant species richness (Rocchini, 2007) or for ecological prediction (Stickler and Southworth, 2008) found that Landsat performed better than IKONOS or QuickBird VHR satellites, across a range of measures of species richness. These studies suggest that this could have serious implications for future habitat modelling, biodiversity analyses and conservation studies — especially given the prior assumption that a higher spatial resolution is necessarily superior. In these studies of biodiversity, it was found that higher spectral resolution is much more important than improved spatial resolution (even with reduced spectral resolution).

Temporal characteristics

A major benefit of using satellite remote sensing for habitat monitoring is that data can be acquired on a regular and repetitive basis, using the same wavelengths, thereby allowing consistent comparisons between images. The frequency of observation by optical spaceborne sensors ranges from several times daily (for coarse spatial resolution sensors, e.g. the National Oceanic and Atmospheric Administration (NOAA) AVHRR) to every 16 to 18 days (e.g. Landsat), although cloud cover, haze and smoke often limit the number of usable scenes (Rosenqvist et al., 2003). A new generation of satellites (Sentinel-2) with a revisit time of five days is expected to be launched in 2015. With a five-day revisit capacity, the two Sentinel-2 satellites will acquire data in different seasons, thereby allowing the temporal variations in reflectance to be exploited for mapping and monitoring natural habitats. Images taken on dates where two species are at different phenological stages allow species to be distinguished and further assist in habitat classification (Lucas et al., 2007 and 2011). Another benefit of the multi-year revisit capacities of satellites is their suitability for assessing changes in habitat (such as loss, degradation and fragmentation) through change detection approaches. Identifying areas of change is useful because it allows subsequent field work to concentrate on these areas, possibly yielding a significant increase in cost-efficiency (Vanden Borre et al., 2011). A fundamental challenge for the study of changes in habitats status is the trade-off between the level of spatial detail and the revisit time provided by the sensor, and the ability to verify the interpretation of phenological activity.

Table 3.3 presents a comparison on how the various remote-sensing techniques (sensors and resolution) can contribute to the mapping of natural habitats at two classification levels: the first for distinction between broad physiognomic types (grass, shrub and tree), and the second for distinction within each broad physiognomic type, with a special category for wetlands.

Obviously, the combination of different suitable sensors would increase the capabilities of information extraction for a given parameter (see the paragraphs below on data fusion).

Cost

One of the main reasons for using remote sensing is its cost-efficiency compared to field surveys. The cost of remote sensing data is a function of a number of parameters: the type of sensor (optical, radar or hyperspectral), the platform (satellite or airborne), the spatial resolution, the minimum area to be ordered, the processing requirements (e.g. orthorectification or simple radiometric correction), and whether an archive is available or a new acquisition is required. Airborne imagery is usually more expensive than satellite imagery; image acquisition costs can be high and need to include aircraft hire, equipment and mount purchases, personnel costs and travel costs. Costs are estimated to be two to three times that of basic QuickBird image acquisition costs (though tasking QuickBird would increase costs). Image mosaiking and georeferencing can be time-consuming and requires skilled operators. It is estimated that half an hour per image would be required to georeference, colour balance and insert into a mosaic. For a reach of 20 images, this would mean approximately 10 hours of work — prior to any classification being undertaken. The cost for such analysis, including purchase of mosaiking and image processing

Table 3.3 Contribution of various remote sensing techniques to the mapping of natural habitats at two classification levels, and at 1:25 000–1:50 000 scales

	Very high spatial resolution (e.g. aerial photos IKONOS, QuickBird, GeoEye, WorldView-2)	Medium-to-high spatial/temporal resolution (e.g. Landsat, IRS, SPOT)	Coarse spatial resolution and very high temporal resolution (e.g. MODIS, AVHRR)	Hyperspectral (e.g. HyMap, CASI, Hyperion)	Laser Scanning (LiDAR)	Active microwave sensors (e.g. SAR)
Level 1 Distinction between broad physiognomic types: grass, shrub, tree	++ (besides open water and bare soil)	++ (besides open water and bare soil)	++ (only in landscapes with large vegetation patches)	++ (besides open water and bare soil)	++	+ (besides open water)
Level 2 Distinction within the physiognomic type Forest	++	+ 3 classes: deciduous/ pines/other conifers	−/+ 3 classes: deciduous/ coniferous/mixed forest	++	−/+ Must be combined with multispectral imagery for mapping forest species ++ Assessment of forest parameters (stand density, height, crown width and crown length)	−/+ Less efficient than multispectral imagery for species identification + Radar-derived information on vegetation structure is complementary to information provided by multispectral imaging
Level 2 Distinction within the physiognomic type Grasslands	+ With multi-seasonal imagery: grassland types with different levels of agricultural improvement	++ With multi-seasonal imagery: distinction between marshy grasslands (*Molinia*- or *Juncus*-dominated), unimproved (*Festuca*-dominated), semi-improved and improved	−	++ Determining the species composition	−	+ Separation between native grasslands and improved pastures (in quad polarisation)
Level 2 Distinction within the physiognomic type Heathlands	++ Seasonal phenological variation can discriminate the evergreen *Calluna vulgaris* from the deciduous *Vaccinium myrtillus*	++ With multi-seasonal imagery: distinction between heath types (e.g. Genista and Erica)	−	++ Distinction between dry and wet heathland, heathland types (*Calluna, Molinia Deschampsia, Erica*, etc.) and heath age classes	−/+ Only if types differ by structure or density	−
Level 2 Distinction within the type Wetlands Note: Wetlands are not a physiognomic type per se, but are various physiognomic types that have adapted to the continuous or temporary presence of water	+ Detection of riparian vegetation species	+ Seasonal imagery allows mapping the spatial extent of seasonally submerged wetlands and some vegetation species	−	++ Distinction between aquatic macrophytes species (*Typha, Phragmites, Scirpus*)	−/+ To be combined with multispectral imagery. High-precision LiDAR-derived digital terrain map is used to build the relationship between wetland vegetation species and associated ground elevation. This may enhance the understanding of the characteristics of different wetland vegetation species	−

Note: The degrees of suitability of the sensor to the identification of a given parameter are:
− = unsuitable
−/+ = more or less suitable
+ = suitable
++ = recommended.

software, should be included in any final method recommendation. Acquisition costs for LiDAR are currently around EUR 130/km² to EUR 150/km². In the mid to long term, wider use of such techniques may lead to reductions in costs. Often some remote sensing data are available at no extra cost to organisations; for example, in France, the national mapping agency Institut Géographique National (IGN) makes available national coverage of aerial photos to all public institutions. Vanden Borre et al. (2011) suggest that a remote sensing product that is lower in thematic detail, but much more up to date than a comparable field survey product may be worth using, especially when it is also cheaper to produce. At the same time, a considerable gain in quality of the data may sometimes justify using a product that is more expensive.

Data fusion

Data fusion techniques and methods integrate information acquired with different spatial and spectral resolutions from sensors mounted on satellites, aircraft and ground platforms to produce fused data that contain more detailed information than each of the sources (Zhang, 2010). Mapping of natural habitats can greatly benefit from the complementarity of broadband multispectral or narrow-band hyperspectral data (aerial or satellite) and radar or LiDAR data, as demonstrated by several studies including rangelands in the United States (Huang et al., 2010), forests in Italy (Dalponte et al., 2008) and grasslands (Bork and Su, 2007).

Integration of optical data from hyperspectral imaging spectroscopy with structural information from LiDAR is believed to hold great promise for improving the accuracy of forest inventory and ecological modelling at landscape scale.

Mapping vegetation with remote sensing: lessons learned

Remote sensing data sets are increasingly being considered by EU Member States, in order to fulfil their reporting obligations under the Habitats Directive (Lengyel et al., 2008). However, the use of satellite-based remote sensing for accurate, detailed and complete conservation status assessment and monitoring of natural and semi-natural habitats, as required under the Habitats Directive, is still rare (Vanden Borre et al., 2011). The potential of remote sensing techniques has been more clearly demonstrated for mapping the physiognomy of vegetation (life form, cover, structure, leaf and type) than for the identification of individual species or communities defined by their floristic composition. The life forms (e.g. herb, shrub or tree) in the dominant or uppermost stratum will predominate in the classification of the vegetation type based on remote sensing data. The physiognomic classes could be used in conjunction with existing physiographic and biological information to provide a framework for a more focused in situ habitats inventory. The coupling of remote sensing and field data can result in an increase in precision and in area estimates of various habitat classes (McRoberts et al., 2002). An example of such a valuable integration is the use of Earth observation-based physiognomic maps for a post-stratification of existing sample-based habitats inventories. The increased precision obtained using post-stratification also means that estimates of areas covered by different habitat classes can be presented for smaller areas than is possible from estimates based only on a sparse sample of in situ data alone, without any reduction in precision (Gerard et al., 2012).

Maps of physiognomic classes could also be coupled with existing species occurrence and conservation data, to provide a basis for a detailed habitat classification. In a more holistic approach, physiognomic maps can be used in conjunction with models (e.g. of species distribution) and field information to predict changes in specific species of interest (Nagendra et al., 2012).

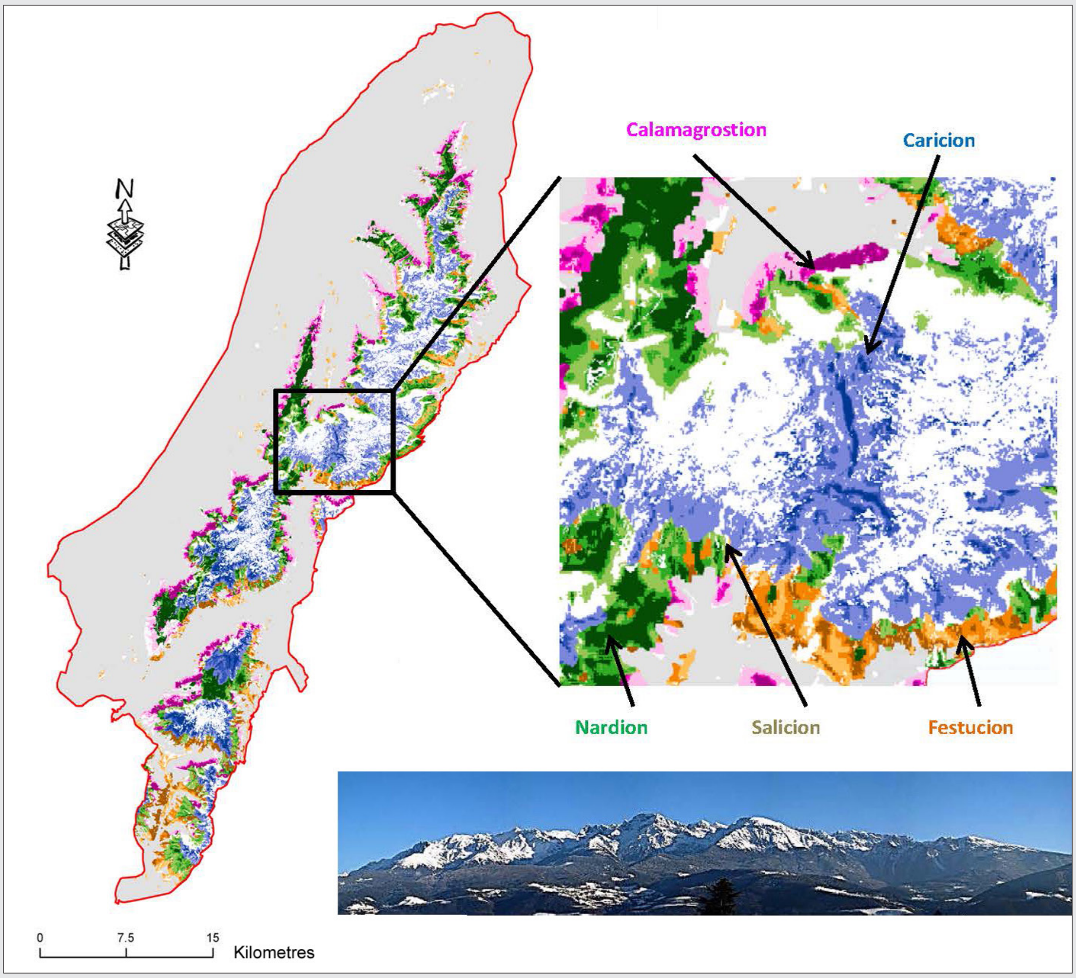
3.4.2 Habitat modelling: prediction of biospatial patterns in relation to environmental gradients

With the rise of new powerful statistical techniques and GIS tools, the development of predictive habitat distribution models has rapidly increased in ecology. Such models are static and probabilistic in nature, since they statistically relate the geographical distribution of species or communities to their present environment. The analysis of the species-environment relationship has always been a central issue in ecology, and the quantification of such species–environment relationships represents the core of predictive geographical modelling. These models are generally based on various hypotheses on how environmental factors control the distribution of species and communities (Jongman et al., 1995; Schuster, 1994; Guisan and Zimmermann, 2000).

Box 3.6 Modelling the distribution of vegetation alliances in the French Alps

As a contribution to the French CarHAB project, MaxEnt (Phillips et al., 2006; Phillips and Dudík, 2008) was used to separately model the distribution of five vegetation alliances as defined by the National Botanical Conservatory of the Alps (CBNA) (see Lambertin; 1999; Mikolajczak, 2011a and 2011b). MaxEnt is specifically designed for presence-only data, and to overcome problems associated with small samples. Further details on the models developed in relation to the example shown below from the French Alps can be found in Redon et al. (2012).

Map 3.1 Mapping the potential distribution of different alliances in the Belledonne mountain range (French Alps)



Study area in the French Alps, Belledonne mountain range

Note: 'Caricion' is *Caricion curvulae,* 'Nardion' *Nardion strictae,* 'Festucion' *Festucion variae*, 'Calamagrostion' *Calamagrostion villosae* and 'Salicion' *Salicion herbaceae*.

Source: IRSTEA.

Within Europe, a wide variety of modelling techniques have been used to model the distribution of species, species groups, guilds, plant communities and habitats, and the most widely used are summarised in Annex 4. However, opting for a particular model is a complex choice; one alternative is to simultaneously and separately run different modelling methods (each with or without iterations) on the same data set for the same initial geographical area of analysis. It is then possible to compare the results in order to select the approach that provides the most consistent results in terms of objectives, or to combine the different results into one final model. The BIOMOD modelling platform was developed specifically for this purpose (see http://www.will.chez-alice.fr/Software.html) (Thuiller, 2003; Thuiller et al., 2009).

Modelling and mapping vegetation species distribution: lessons learned

The best way forward in modelling vegetation and habitat distributions is to combine top-down modelling with bottom-up knowledge. However, exploitation of bottom-up knowledge demands considerable efforts in terms of data collection and harmonisation. Selecting the right modelling approach for a specific project can be difficult, and it is important not only to have clear aims but also to have identified stakeholders' needs and possible responses — this remains key to the selection of scales and type of spatial habitat model(s). Reliability of the models should be a main issue in ecosystem domain applications, giving priority to the development of dynamic response models.

The use of remote sensing and geoinformation is important for reducing uncertainty in the modelling domain. But before they start to work together, field ecologists and remote sensing groups need to understand each other and to have a common language.

3.5 Key references

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4 The survey on habitat mapping initiatives in Europe: a general overview

Chapter 4 summary

This chapter introduces the results of a survey on habitat mapping in Europe conducted by the MNHN and the ETC/BD for the French ministry responsible for the environment. Intended to be as comprehensive as possible, it was based on a bibliographical review (317 references), a questionnaire addressed to 40 European countries and a series of semi-structured interviews: of the 163 inventoried projects, 65 were selected for study. A general overview of the most important habitat-mapping initiatives in Europe follows directly, and in the next chapter (Chapter 5), the mapping methodologies identified within the survey are discussed. Some of the most important projects are discussed in greater detail, as case studies (e.g. from the Czech Republic, Spain, Italy and Hungary). Appendix 2 summarises the mapping programmes studied.

4.1 Material and methods

The survey combined bibliographical reviews, customised (individual) questionnaires and a series of semi-structured interviews. The organisation was validated by a working group of representatives of the CarHAB technical committee and the ETC/BD, taking into account the following issues:

- no comprehensive overview of large-area habitat mapping in Europe was available;
- access to much of the literature is problematic (e.g. grey literature and language issues);
- methodological aspects are rarely discussed (Molnár et al., 2007).

Design of the questionnaire

The questionnaire contained 107 fields arranged in 7 major categories: general context, organisation/governance, methodology, information systems, data analyses and diffusion, funding, uses and applications. Concerning the questions, 53 were considered obligatory and 54 optional, and there were 2 types: (i) closed, allowing analysis of the responses; and (ii) open-ended, to allow more detailed information to be gathered.

The targets of the questionnaire were experts with a national or regional knowledge on habitat mapping, predominantly vegetation scientists and project managers in conservation agencies. Contacts were collected through several networks, in particular the EEA, ETC/BD, MNHN, the EVS and the CarHAB technical committee. Where there were obvious gaps in coverage, contacts were sought on the Internet.

Before being sent, each questionnaire was prefilled based on information from bibliographic sources.

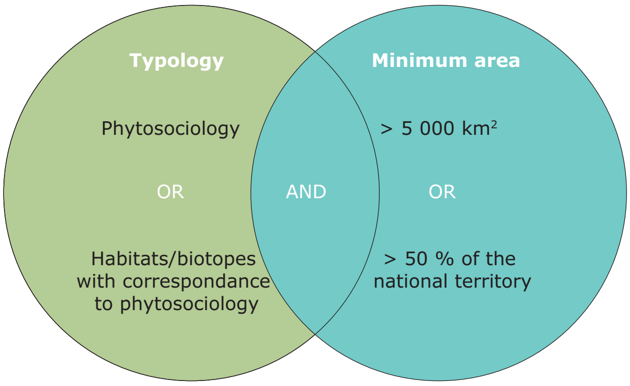
Semi-structured interviews

A series of semi-structured interviews were conducted with a selection of correspondents. This format allowed flexible questioning within a prepared framework. The first objective was to ascertain if the national lists of mapping programmes were exhaustive, complete missing information, harmonise the answers and obtain additional contacts when necessary. The second objective was to obtain feedback relevant to the CarHAB project.

Filters

The main objective of the survey was to identify habitat mapping programmes which had mapped large areas. The bibliographical review revealed a wealth of mapping schemes of varied scope and geographical coverage (n = 163). A filter was applied in order to target programmes of greatest interest to CarHAB and to obtain a relatively exhaustive sample.

Figure 4.1 Filter used for the survey



Projects selected for further study were:

- **national or regional projects** where the mapped area was greater than 5 000 km² or covered at least 50 % of the national territory;
- **those based on a phytosociological approach** or using a typology compatible with phytosociology, i.e. containing at least one reference to phytosociological classifications in the legend or in the typology; this excluded land use and land cover surveys.

However, other programmes considered important by experts were also included in the database and used for certain analyses.

Validation process

Two types of validation were applied for the survey. First, the respondents were asked if the information could be considered comprehensive for their country, as far as they were aware. A second validation was performed through the EEA's European Environment Information and Observation Network (Eionet). Both Eionet National Reference Centres (NRCs) on nature and biodiversity and NRCs on forests were consulted. Feedback was received from 11 countries.

4.2 Bibliographical review

A total of 306 references were collected, 133 of which were directly used in the survey.

The principal literature types were books and published reports (49 %), scientific articles (37 %), unpublished reports and other grey literature (10 %) and conference proceedings (4 %). Scientific papers were published in both national (65 %) and international (35 %) journals. Figure 4.2 shows which academic journals were noted in the survey and the number of articles per journal.

Scientific publications are an essential source of information about important mapping programmes; the information is peer-reviewed and widely accessible. The results of mapping programmes were more likely to be published in national rather than international journals, although a growing number of papers are being published on subjects related to vegetation mapping in international journals. They concern vegetation surveys (e.g. *Plant Biosystems*, *Applied Vegetation Science* and the *Journal of Vegetation Science*), remote sensing (e.g. the International Society for Photogrammetry and Remote Sensing (*ISPRS) Journal of Photogrammetry and Remote Sensing*) or applications of the results in other fields of ecology (e.g. the *Journal for Nature Conservation*, *Biodiversity and Conservation*, *Biological Conservation*, *Community Ecology* and *Ecological Complexity*).

Grey literature includes many technical reports and working papers, and is an essential source of information on habitat mapping outside conventional publication channels, although some publications are difficult to access. Final reports of important projects are frequently made available on the Internet, but online grey literature databases, such as the French Bibliothèque de littérature grise des Conservatoires Botaniques Nationaux (see http://www.fcbn.fr/documentation/opac_css/index.php?lvl=search_result), are rare.

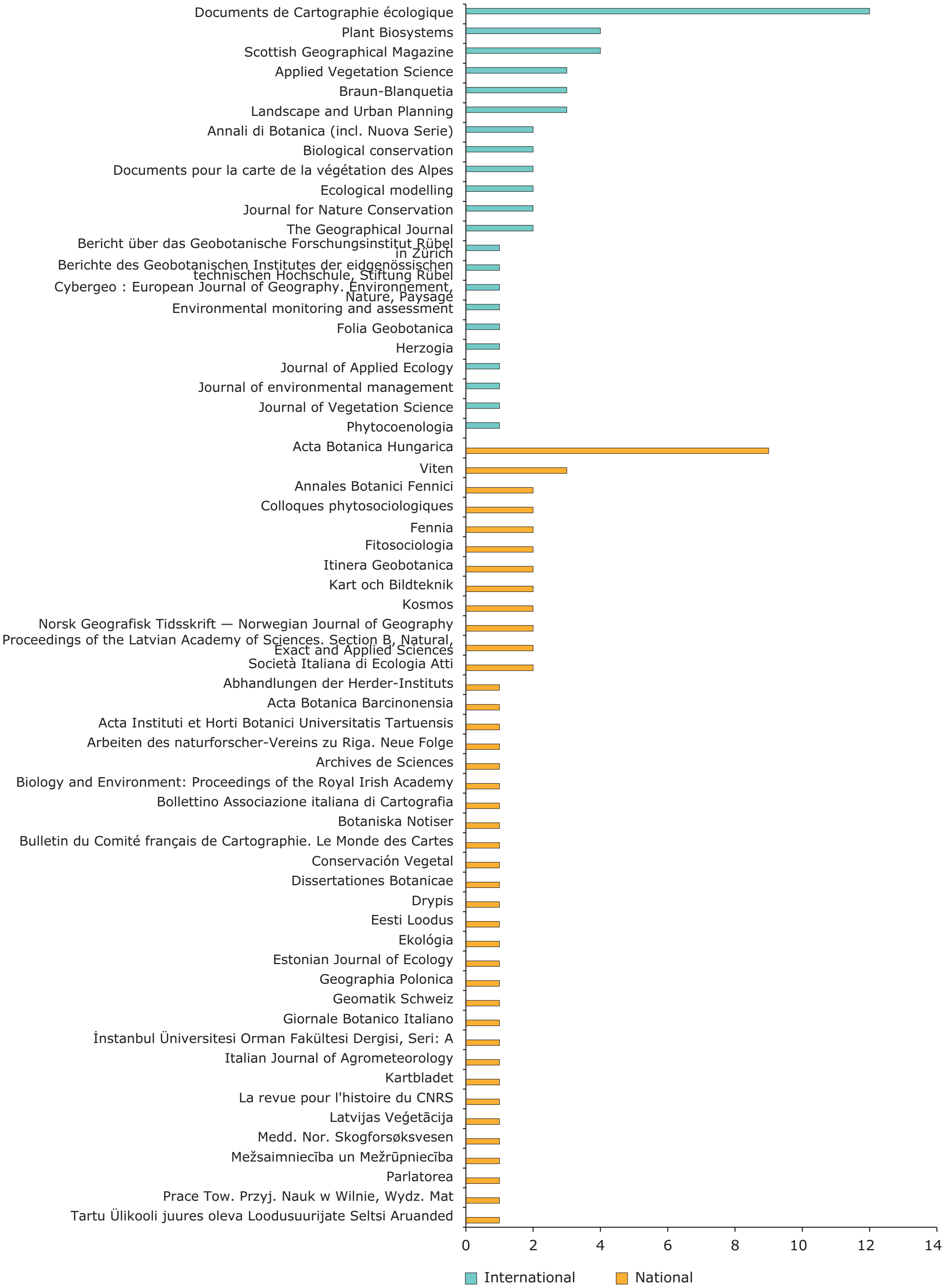
4.3 Coverage of the survey

The survey covered 40 European countries; 27 EU Member States, 5 non-UE EEA member countries (Iceland, Liechtenstein, Norway, Switzerland and Turkey), the 7 West Balkan EEA collaborating partners (Albania, Bosnia and Herzegovina, Croatia ([5]), the former Yugoslav Republic of Macedonia, Montenegro, Serbia and Kosovo ([6])) and Andorra.

A total of 29 countries responded to the questionnaire (72 %), and results for 11 countries were based purely on literature sources.

([5]) The survey was carried out in 2012 and Croatia joined the EU in 2013.
([6]) Under UNSCR 1244/99.

Figure 4.2 Academic journals mentioned in the survey

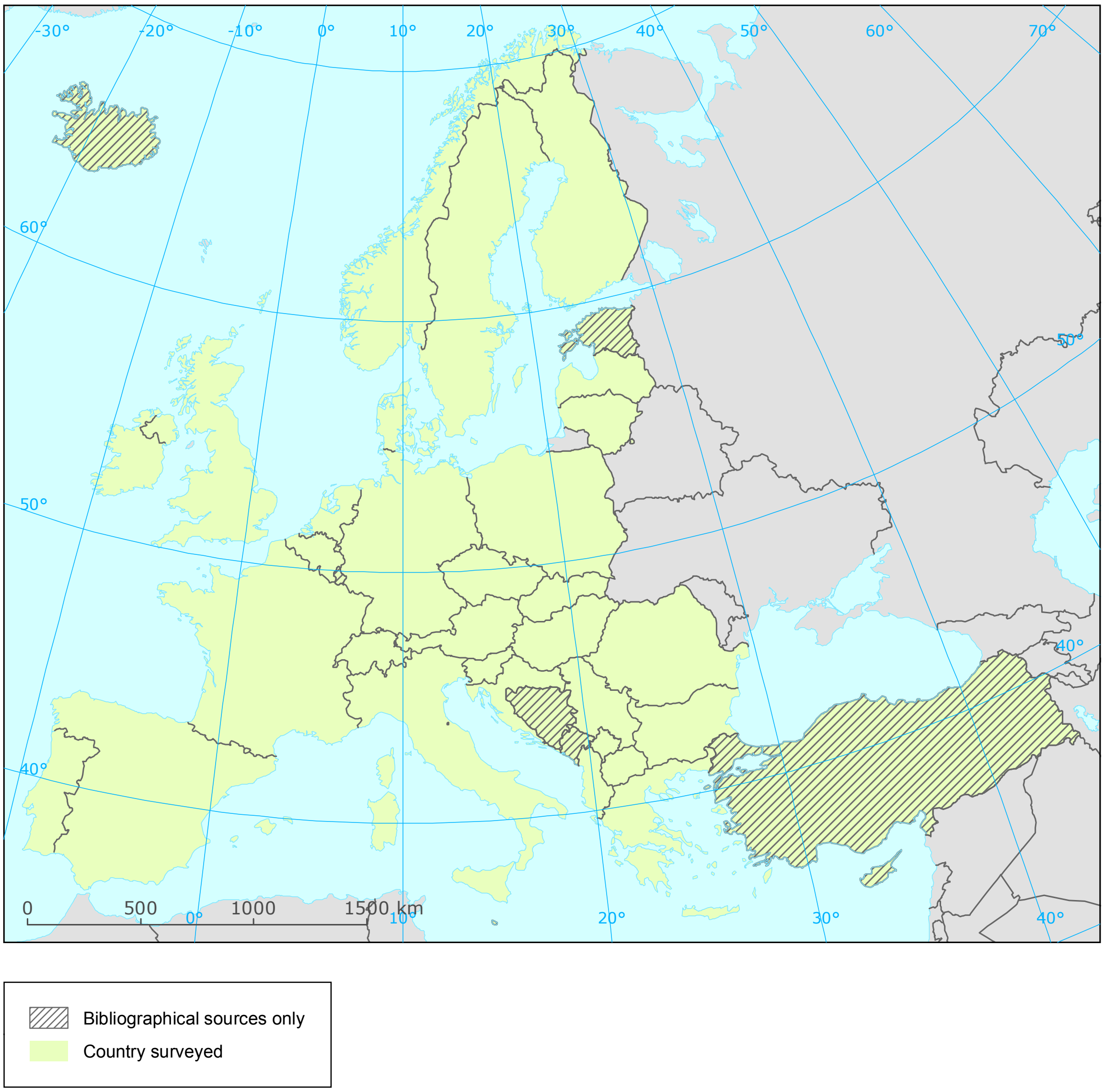


Some 115 experts, mostly vegetation scientists and project managers in conservation agencies, were contacted for the survey, and 39 semi-structured interviews were conducted. In total, 163 projects were inventoried, 65 of which were considered to fall within the scope of the survey. A list of projects selected for the survey and key experience is given in Annex 1, while Annex 3 provides a synthesis of the main features of the selected programmes by country.

4.4 Analysis of key features of the selected projects

There is a great variety of large-area habitat-mapping projects in Europe. Their key features are presented here: their geographical extent, the types of habitat mapped, their scale, project management and project duration.

Map 4.1 Coverage of the survey



Source: MNHN, ETC/DB.

4.4.1 *Geographical extent*

- **Transnational (3 %)**

  Transnational mapping projects are rare and often at small scale. At European level, two maps of potential natural vegetation (PNV) are available: one at a 1:1 500 000 scale (Bohn & Neuhäusl 2003) and the second at a 1:3 000 000 scale (Noirfalise 1987). In terms of coverage, the former covers all of Europe but excludes Cyprus and Turkey south of the Bosphorous, while the latter covers Cyprus and Turkey but not the former Soviet bloc (see Section 2.4).

  Other projects at larger scales exist (e.g. Corine Land Cover), but they concern land cover or physiognomic types, and therefore were not included in the first level of the survey. Habitalp, another important transnational programme, was a cooperation project conducted between 2002 and 2006 within the Alpine Network of Protected Areas under the Alpine Convention. Its main objective was to develop a transnational database on alpine landscapes in terms of structure, diversity and evolution, with a particular focus on Annex I habitats (Lotz, 2006). Although it is an important initiative, the mapped area is smaller than 5 000 km² (4 300 km²) and thus it was not used directly in the survey.

- **National (66 %)**

  Most of the selected projects function at this level; it is considered as the most suitable level of organisation for large-area mapping schemes in terms of data management (see Section 4.4.6) and methodological harmonisation (see Section 5.9), as it produces more homogeneous results and allows better data control and circulation. The most important projects in terms of coverage and fieldwork are the national biotope mapping initiative of the Czech Republic (see Box 4.1), the Hungarian MÉTA programme (see Box 4.4), the Carta della Natura in Italy (see Box 4.5) and the Natura 2000 habitat inventory and mapping in Spain (see Box 6.1).

- **Regional (25 %)**

  In countries where nature conservation is a regional competence, habitat mapping is frequently organised at regional scale, either by true federal states (e.g. Germany, Austria and Belgium) or by countries with autonomous regions (e.g. Spain and the United Kingdom). It is considered an efficient level of organisation, since surveyors are more likely to work in a similar manner within the same region. However, when aggregating regional data at national scale, problems frequently arise.

  In terms of typology, few such countries have adopted one national classification (e.g. the National Vegetation Classification in the United Kingdom), and most countries have regional typologies. In some cases, important efforts have been made to establish a common framework allowing crosswalks (e.g. *Biotopkartierung* in Germany), whereas in other countries such as Spain, regional classifications are largely incompatible with each other.

- **Site-based (6 %)**

  Some countries have focused their mapping activities on protected areas; this is particularly true of Natura 2000 sites in the EU. Member States need to report on the extent of habitats of Community interest within each site, and maps form an important component of management plans. We only included those countries that applied a common national mapping methodology, and cases where the total area mapped was sufficient (> 5 000 km²). Unsurprisingly, the countries selected were those with a high proportion of their national land territory covered by Natura 2000 sites, i.e Bulgaria (34 %) and Greece (27 %).

  In Bulgaria, an inventory focused on 86 Annex I habitats at a 1:5 000 scale. Due to the size of the project (33 300 km²) and the limited time available (March 2011 through March 2013), the project was not based on detailed fieldwork, but rather on a combination of field mapping together with validation of previously prepared models.

  In Greece, an important project aimed to identify, describe and map all habitat types in all 237 terrestrial Sites of Community Importance (SCIs) (20 000 km²; see Section 5.1). The project (1999–2001) was mainly designed for inventory purposes including detailed characterisation of the vegetation communities and mapping. A second project (2013–2015) is using the same methodology but with a focus on monitoring.

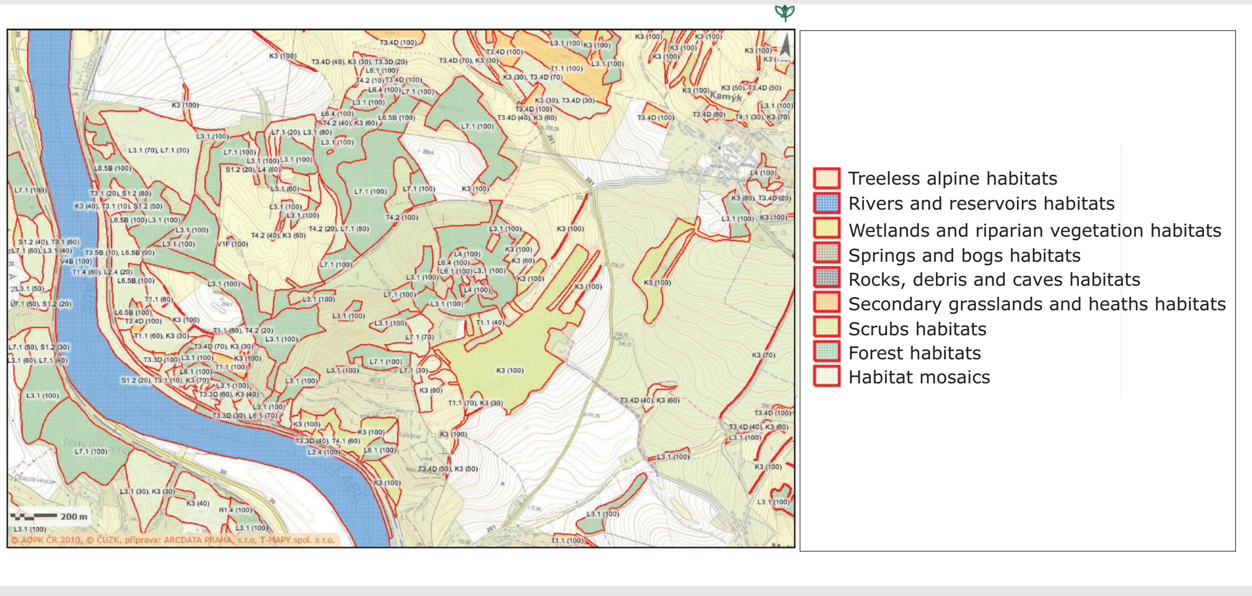
Box 4.1 Case study: biotope mapping of the Czech Republic

The Czech biotope mapping programme is an ambitious project initially set up to aid the establishment of the Natura 2000 network. However, its significance has far exceeded the original aim of acquiring data so as to identify SCIs.

Habitat mapping was based on the classifications described in the Biotopes Catalogue of the Czech Republic (Chytrý, Kučera and Kočí, 2001) (see Section 5.1). Mapping carried out at a 1:10 000 scale allowed identification of Annex I habitat types for Natura 2000 sites designation. More than 750 persons were involved in the mapping process, and the quality of individual surveys was heterogeneous, despite strict compliance with the methodology. In order to synchronise the classification of biotopes and the assessment of their representativity and conservation status, training events and field trips were organised, both at regional and national level, along with field checks in the sites surveyed. The first habitat mapping was completed in 2004. Some major mistakes in the habitat mapping layer were corrected immediately in the year 2005, in a process called rectification performed by national experts on the basis of random field checks.

The biotope mapping produced very useful information, not only concerning habitats of Community interest; for the first time in the history of Czech nature conservation, it gathered data on all natural habitats types and their distribution across the entire country. The biotope mapping layer represents an extremely useful resource, providing summary data and analyses for projects and reports that require data for the whole Czech Republic. The results were also used as a basis for Natura 2000–appropriate assessments and for environmental impact assessment, as well for scientific research, theses or decision-making procedures. Specific projects (e.g. the Red Book on biotopes of the Czech Republic) represent another important use of the biotope map. Nevertheless, it is primarily and most importantly used as a basis for identifying SCIs and as a data source for reporting under Article 17 of the Habitats Directive for Annex I habitat types (see Section 5.5.1).

Map 4.2 An example of a Czech Republic biotope map



Source: AOPK ČR.

4.4.2 *Thematic scope (type of habitats mapped)*

- **All habitats (i.e. natural, semi-natural, agricultural and artificial) (22 %)**

  Some programmes cover the entire survey area, regardless of habitats. In this case, the thematic precision is generally very variable. Agricultural and artificial landscape are more coarsely defined since they are simpler to characterise and less biodiverse. However, in less intensively managed landscape, the ecological role of those habitats can be significant, for example in terms of secondary habitat or ecological corridors. Another aspect to consider is the area covered. Including agricultural and artificial land may substantially increase the extent of a project. For the French habitat-mapping programme CarHAB, it was estimated that including agricultural land would increase the area to be mapped by about 37 %.

- **Natural and semi-natural habitats (58 %)**

  Natural habitats are considered the land and water where the ecosystem's biological communities are formed largely by native plant and animal species, and where human activity has not essentially modified the area›s primary ecological functions. Semi-natural habitats can be defined as areas managed, modified or created by human activity, but still functioning as an ecosystem with specific fauna and flora. Traditional activities (mostly extensive agriculture, see Halada et al., 2011) are the main factor instrumental in maintaining these habitats. The distinction between semi-natural and agricultural/artificial is not always evident, and is best determined by species composition and/or indicator species. It is the most commonly used type of thematic scope: it is considered to represent an efficient balance between time-consuming full-coverage maps and incomplete thematic maps.

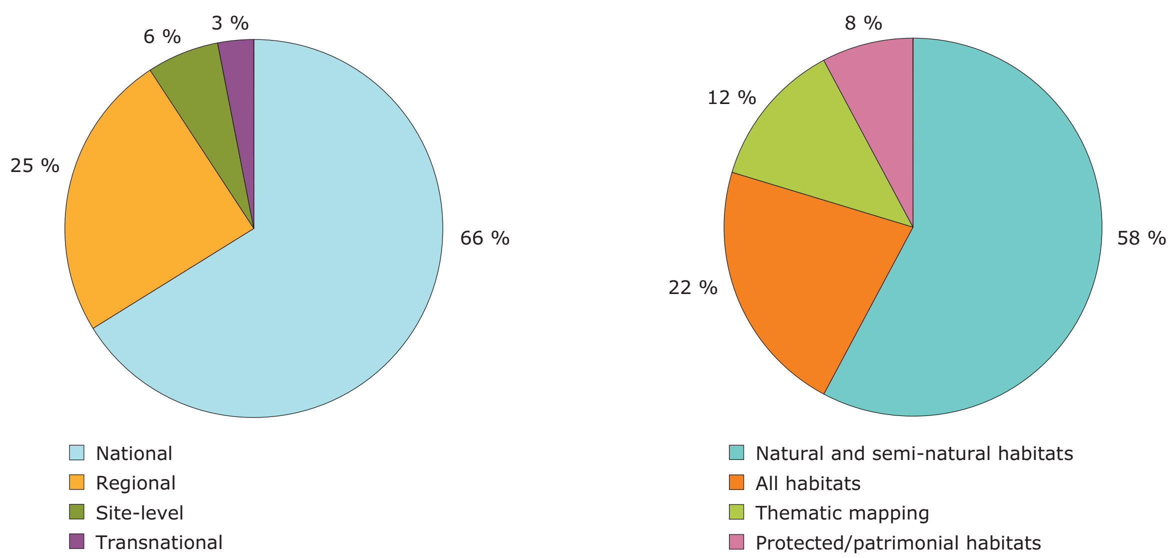
- **Protected habitats/habitats of natural heritage value (8 %)**

  Another approach for habitat mapping is to focus on habitat types which are legally protected or of natural heritage value. This priority is justified firstly by the legal obligation to have a spatially explicit knowledge of their distribution, and secondly by the assumption that they require special attention. Habitats of Community interest as listed in Annex I of the Habitats Directive are those protected by the Habitats Directive in the EU, while Resolution 4 of the Bern Convention provides the equivalent list for the Emerald Network. Some national and regional authorities have also published their own lists of protected habitats (e.g. Germany).

- **Thematic mapping (habitat types)**

  This is a common type of mapping, especially for forests, grasslands and wetlands. However such types of mapping initiatives are not well represented in this survey (12 % of the projects), because many are of low thematic precision (e.g. forest stands) or cover insufficient areas (e.g. peatland mapping).

Figure 4.3 Geographical extent (left) and thematic scope (right) of the selected projects



4.4.3 *Different scales for different objectives*

A map is a representation of the world and cannot depict its true complexity: it is produced for a specific objective. Therefore a balance must be found between spatial precision (i.e. the scale), thematic precision (i.e. the type of object mapped and the level of detail of the typology) and the extent of the map.

Figure 4.4 highlights the trade-off between key features for three representative examples of mapping programmes in Europe: Biotope mapping of the Czech Republic (see Box 4.1), the Map of the Vegetation series of Italy (see Section 7.5), and habitat/vegetation mapping of Catalonia, Spain (see Box 4.3).

Box 4.2 Concepts of scale(s) and resolution

Scale is the ratio of a distance on a map to the corresponding distance on the ground. For example, a scale of 1 to 25 000 (i.e. 1:25 000) means that 1 cm on the map is equal to 25 000 cm or 250 metres on the ground. There is a direct link between the scale of a map and the smallest objects that can be delineated. It is generally considered that polygons smaller than 4 mm² cannot be easily distinguished on a map, and therefore that the minimum size of a polygon on a 1:25 000 scale map should be 2 500 m². Depending on the symbols used (e.g. solid colour or hatches), larger sizes of polygon may be used to ensure decent map readability. The accuracy of polygon outlines (the smallest distance between two points, i.e. vertices, on a line segment) also depends on the scale of a map. More vertices are needed to accurately position polygon outlines on large-scale maps (e.g. 1:10 000 maps, with a scale ratio closer to 1) than on smaller scale maps (e.g. 1:100 000 000).

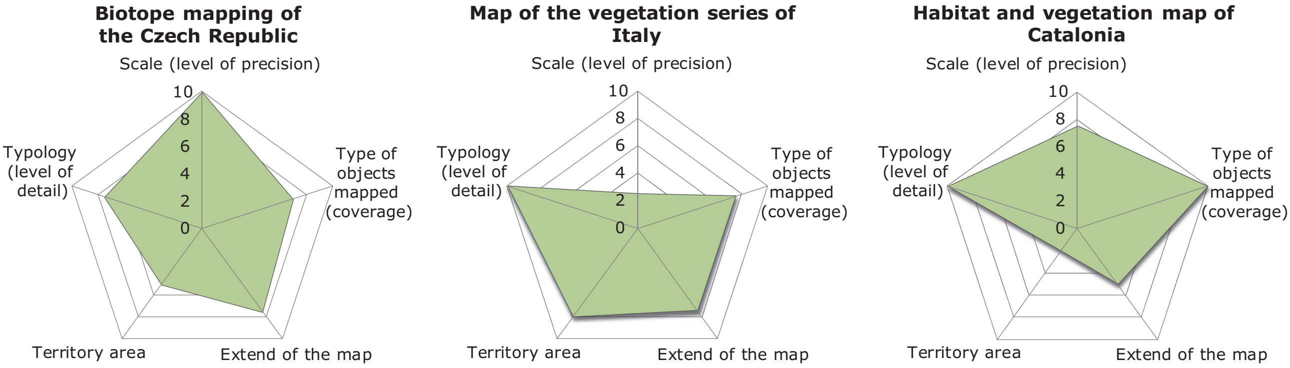
Today, geographical information systems and spatial databases allow free zooming, so the question of the scale is less of an issue. However, the accuracy of data acquisition defines at which spatial scale a database can be optimally used, and the questions of polygon minimum size and level of outline detail still need to be addressed.

Depending on the scale, the way real-world objects are expressed on the map (i.e. point, line or polygon) varies. A habitat patch may be represented by a polygon on a large-scale map or by a point at smaller scales; similarly, a linear habitat (e.g. a river or a hedgerow) will be drawn as a polygon at large scale and as a line at smaller scale. These differences in representations generate changes in the nomenclature, which makes the multiscale use of databases a noteworthy issue. The changes of scale are governed by specific processes called generalisation (see Section 4.4.6).

Projection

Scales can be considered accurate across the entire map of small areas, but this does not apply to maps representing large areas. Maps are plane representations of the Earth, whose shape is roughly a sphere. Mathematical transformations, called projections, are used to convert coordinates of a point on the Earth's surface (latitude and longitude) into coordinates in the plane of the map (e.g. Cartesian coordinates: x and y). But each projection has its specific areas of distortion where the ratio between ground and mapped distances (i.e. the scale) varies. However, these variations may not be significant when compared to the spatial accuracy of features that are not clearly delimited in the real world (e.g. soil types or wetlands).

Figure 4.4 Main types of mapping schemes according to key features



Note: For the type of objects mapped and extend of the map see categories in Section 4.4.1. For typology 1 = Land cover, 2 = habitats/biotopes classifications without correspondence to phytosociology, 3 = habitats/biotopes classifications with correspondence to phytosociology, 4 = phytosociological classifications.

Box 4.3 Case study: habitat and vegetation mapping in Catalonia, Spain

Mapping the environment is a logical continuation of floristic and phytosociological studies in Catalonia in the second half of last century. In 1985, a research team from the Department of Botany of the University of Barcelona began the Vegetation Map of Catalonia project (VMC50), which covers 32 000 km^2 in 89 sheets at a scale of 1:50 000. The creation of the Natura 2000 network required additional environmental information on habitats, and so between 1998 and 2003, the Catalan government (Generalitat de Catalunya) funded the Map of Catalan Habitats project (CHC50). Both projects (VMC50 and CHC50) have now been merged into a single GIS, and this product is widely used as a tool in land management (see http://www.ub.edu/geoveg/en/mapes.php).

The Vegetation Map of Catalonia 1:50 000 (VMC50)

The VMC50 was based on 350 bibliographical references containing around 20 000 phytosociological *relevés* and is based on intensive fieldwork, manual photo-interpretation of ortho-images on the screen and a legend based on a phytosociological typology. This project covers the entire region (i.e. 32 000 km^2). The result is a three-layer GIS describing actual (i.e. real) vegetation, potential vegetation (vegetation series) and vegetation physiognomy (for example, a forest map with the dominant tree species).

The actual vegetation has a posteriori original legend, that is to say, one made during the fieldwork when the surveyor must assign a vegetation code to each ecologically homogeneous area of the territory. In this process, a distinction is made between the following.

(i) Simple units that cover a polygon.

(ii) Vegetation mosaics that include plant communities belonging to different vegetation series that cannot be resolved as a single unit at this scale.

(iii) Temporal mosaics (called *complexides)*, which are mapping units with communities that belong to the same vegetation series and therefore correspond to a tessela. These legend units are highly analytical; the text is relatively complex, very descriptive with syntaxa, and aimed at two audiences: phytosociologists and non-specialist users.

Units of potential vegetation generally correspond to associations, but may also correspond to sub-associations, or sometimes to a complex of associations. Physiognomic units give a simple representation of the vegetation, based on the dominant species and land cover types.

Box 4.3 Case study: habitat and vegetation mapping in Catalonia, Spain (cont.)

The Map of Catalan Habitats (CHC50)

The Map of Catalan Habitats was produced between 1998 and 2003, following on from experience with the vegetation map. This project is conceptually (and methodologically) very similar to VMC50, but very different in terms of its form and its appearance. Significantly, this map is designed for use by non-technical users, without any simplification of the content needed.

Main features

The most important feature of this project is a polygon layer with information on habitats. It has two legends: one uses the Corine biotopes habitats classification (CEC 1991) established prior to fieldwork, and the other uses Annex I of the Habitats Directive, based on the Interpretation Manual of European Union Habitats. To solve the problem of mosaics, each polygon may have up to three habitats, with their relative cover noted. The minimum area is fixed at 2.25 ha and the delineation of polygons is made on the screen using digital ortho-images in colour and IRC. This projects covers c.32 000 km2.

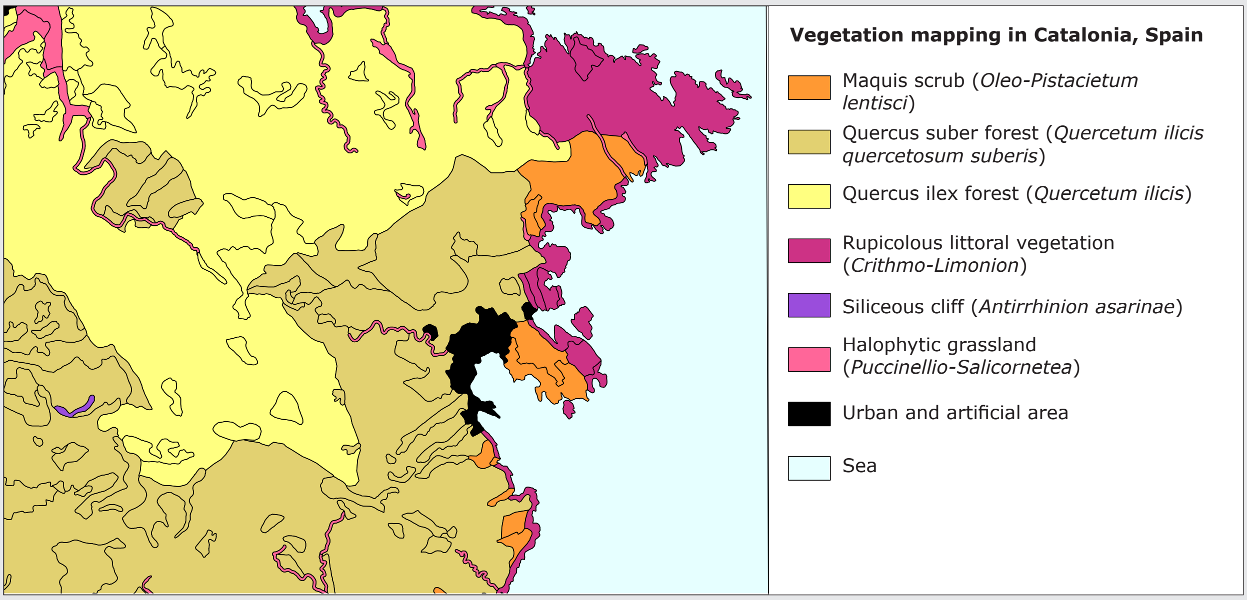
Corine habitat legend

The map legend was an extension of the 1991 Corine biotopes classification, and covers all habitats present in Catalonia, 440 habitats from the original Corine classification and 200 additional habitats (see http://www.ub.edu/geoveg/en/ManualCorine.php). Many of these Corine habitats cannot be mapped at a scale of 1:50 000 because they always cover very small areas. Therefore, a new legend was created for mapping with a new codification. We distinguish habitats that can be represented at this scale individually from those that cannot be represented unless they are grouped together. This new map legend includes 270 units. For Corine habitats which can never be represented at 1:50 000 but may play an important role (some of them may be very rare, others are HCI), we have created a Complementary Map based on a point coverage (without scale) which contains the known locations of these habitats by specifying the area covered in the database.

Annex I legend

The Annex I legend is directly derived from the EU Interpretation Manual but is adapted for Catalonia.

Map 4.3 Extract of the vegetation mapping in Catalonia, Spain



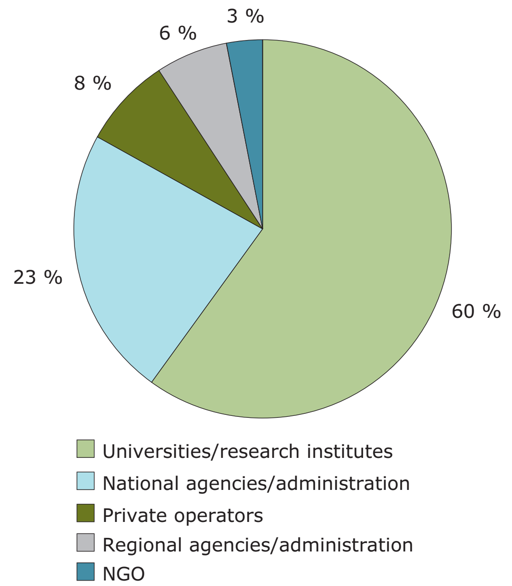
Source: Geoveg.

4.4.4 *Project management*

Project management is the form of organisation adopted to operate a programme and organise the partners in order to meet objectives. It includes all phases of a programme, from the initial planning to the publishing or dissemination of the final product(s).

The complexity of the organisation depends on the size and context of the programme. Project leadership is traditionally shared between project owner and project manager; although in some cases, one organisation can perform both functions. For large mapping schemes, many stakeholders are likely to be involved, and governance should be planned from the start. Often, part of the organisation and decision-making is delegated to a steering committee.

Figure 4.5 Main types of large-area mapping project managers



Project owner and project manager

The project owner is the structure that initiates the project, finances it, identifies the project manager and benefits from its outputs.

The project manager or project commissioner is the person or structure heading the project planning and execution. The project manager is in charge of the budget, the planning, and the coordination between partners. The most frequent types of project managers (see Figure 4.5) are described below.

- Universities/research institutes (60 %). Traditionally vegetation mapping is carried out by researchers. Large-area mapping programmes involve a variety of applied sciences including disciplines related to geobotany, e.g. vegetation science, geomatics and landscape ecology. Today, in countries such as Italy, Spain, Hungary and Romania, most vegetation mapping is still performed by universities or research institutes.

- National agencies/administration (23 %). A national agency or administrative body (e.g. a ministry) is often the project owner of important mapping schemes. In some cases, national agencies are responsible for the coordination of habitat mapping at national level, e.g. the Nature Conservation Agency of the Czech Republic, or the Swedish Environmental Protection Agency and the Institute for Environmental Protection and Research (ISPRA) in Italy.

- Private operators (8 %). In federal countries such as Germany, Spain (Basque country and Aragon) and Austria, some regions delegate project management to contractors. In Ireland, many habitat-types surveys are carried out by consultants under contract from the national parks and wildlife service (e.g. native woodlands, semi-natural grasslands, and salt marshes).

- Regional agencies/administration (6 %). For federal countries such as Belgium and decentralised countries such as the United Kingdom, nature conservation agencies function at regional level.

- Non-governmental organisations (3 %) such as the Institute of Applied Ecology (DAPHNE) in Slovakia and the Centre for Cartography of Fauna and Flora (CKFF) in Slovenia.

Steering committee

Many projects have a steering committee representing the different stakeholders and fields of expertise. The main task of the steering committee is to provide guidance on key issues, in close collaboration with the project manager.

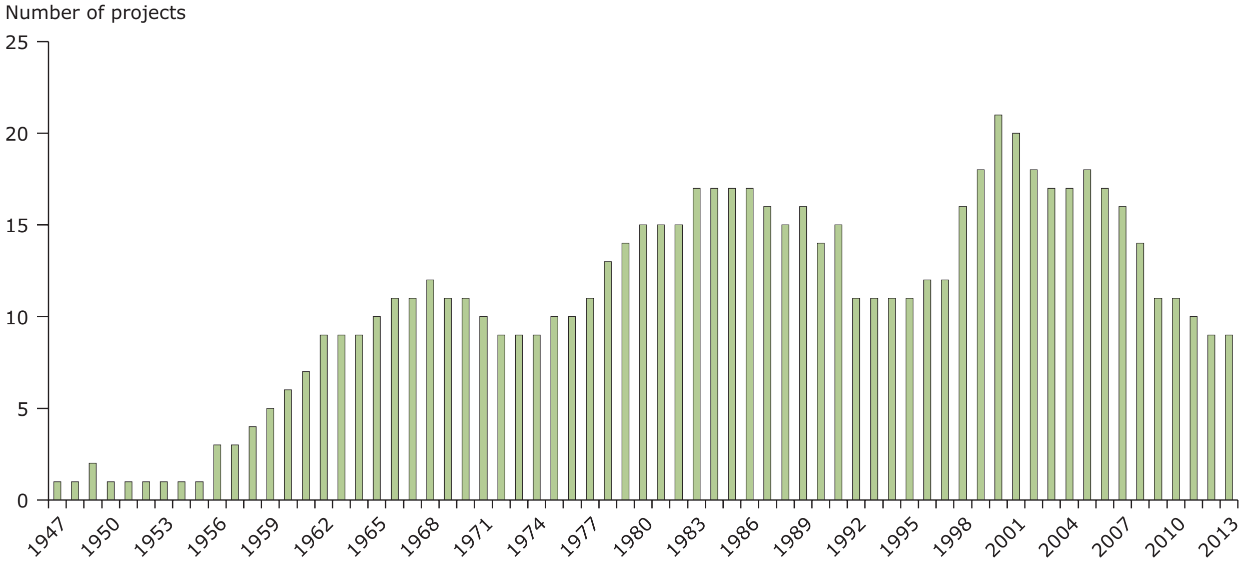
The main functions of the steering committee are to:

- ensure cooperation between partners within the programme;

- define the scientific and technical orientation(s) of the programme;

- ask for relevant external expertise when necessary;

Figure 4.6 Number of projects completed or ongoing per year



- give mandates to commissions or working groups;
- review and validate production and deliverables;
- ensure coordination with related projects and partner institutions;
- define the communication strategy of the programme.

The composition varies according to the context, but it usually comprises at least representatives of the funding body (e.g. ministry) and the main technical partners (e.g. vegetation scientists, GIS specialists, and practitioners). Other project partners may be invited, but the number of members must be limited for efficient decision-making.

4.4.5 Dates and duration of the projects

Dates

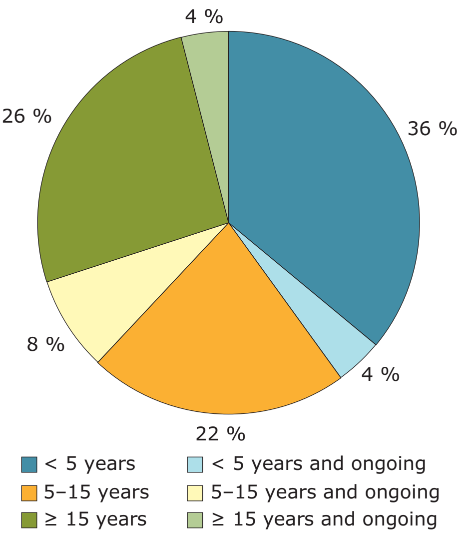
The oldest maps selected for this survey were PNV maps from the 1950s (Albania, former Czechoslovakia and Italy); however, half of the projects started after 1988. Figure 4.6 presents the number of completed or ongoing projects per year, and clearly shows an important increase of projects after the adoption of the Habitats Directive in 1992. As well as demanding information on Annex I habitats, the directive was accompanied by funding opportunities (e.g. the EU-funded LIFE programme). Many countries took the opportunity to improve their knowledge on habitats and their distribution. This trend was accentuated with the EU accession of central and eastern European countries in 2004 and 2007. Technical improvements in GIS may also help explain the increase in project numbers from the mid 1990s.

Duration

Project duration ranges broadly (Figure 4.7): more than a third of the programmes (36 %) last less than 5 years, 22 % between 5 and 15 years and 26 % more than 15 years.

When determining project duration, both objectives and resources (human and material) are important factors. Our results highlight the fact that programmes which are either too long or too short may face certain problems.

Figure 4.7 Duration of large-area mapping projects in Europe



Box 4.4 Case study: the MÉTA programme in Hungary

The main objectives of the Hungarian habitat mapping programme known as Database and Map of Hungarian Habitats (MÉTA) were to map the natural vegetation of Hungary and build a habitat database (Molnár et al., 2007; Horváth et al., 2008). The project, funded by the Hungarian government, was the largest programme focused on vegetation in Hungary. The project started in 2002; following a year of methodology elaboration, most of the field survey work was carried out between 2003 and 2005.

All areas of Hungary (93 010 km^2) with vegetation of natural heritage interest were mapped. In these areas, all natural and semi-natural habitat types were documented, even if they were degraded. However, crops, settlements, non-native tree plantations and open waters were excluded, as they were not considered to be vegetation with natural heritage interest.

The project used a national habitat typology, the Hungarian General National Habitat Classification System (ÁNÉR) which was updated before and after the MÉTA project (Bölöni et al., 2003 and 2011). The ÁNÉR habitat classification system is partly compatible with European typologies (EUNIS, Corine biotopes, Annex I), but the specialities of the Pannonian vegetation are also taken into consideration (Bölöni et al., 2007).

MÉTA mapping was based on a hexagonal grid, and thus the database does not have a scale, but rather a resolution (35 ha hexagons as a basic level, and 3 500 ha large quadrants). The scale is approximately 1:200 000.

MÉTA mapping used a combination of field survey and satellite image interpretation (SPOT4). Surveyors had to survey all hexagons where natural vegetation covered at least 20 % of the area. Around 200 qualified field surveyors were contracted. To ensure data quality, a qualification process was developed (see Molnár et al., 2007) and data were evaluated by regional leaders and national experts (Bölöni et al., 2008a; Molnár et al., 2008a).

The survey results are managed in a centralised relational database containing around 1 500 000 records and are partly accessible on a website (see http://www.novenyzetiterkep.hu/). A web-based application was made available for researchers, allowing the development and the storage of SQL query statements (for details, see Horváth and Polgár, 2008).

The results of MÉTA mapping were published in a special volume of *Acta Botanica Hungarica* in 2008. A book on Hungarian habitats (Bölöni et al., 2011) provides detailed descriptions (including maps and pictures) of all mapped habitats, while a photo guide helps non-botanists to identify Hungarian habitat types (see http://www.novenyzetiterkep.hu/fototar/index.html).

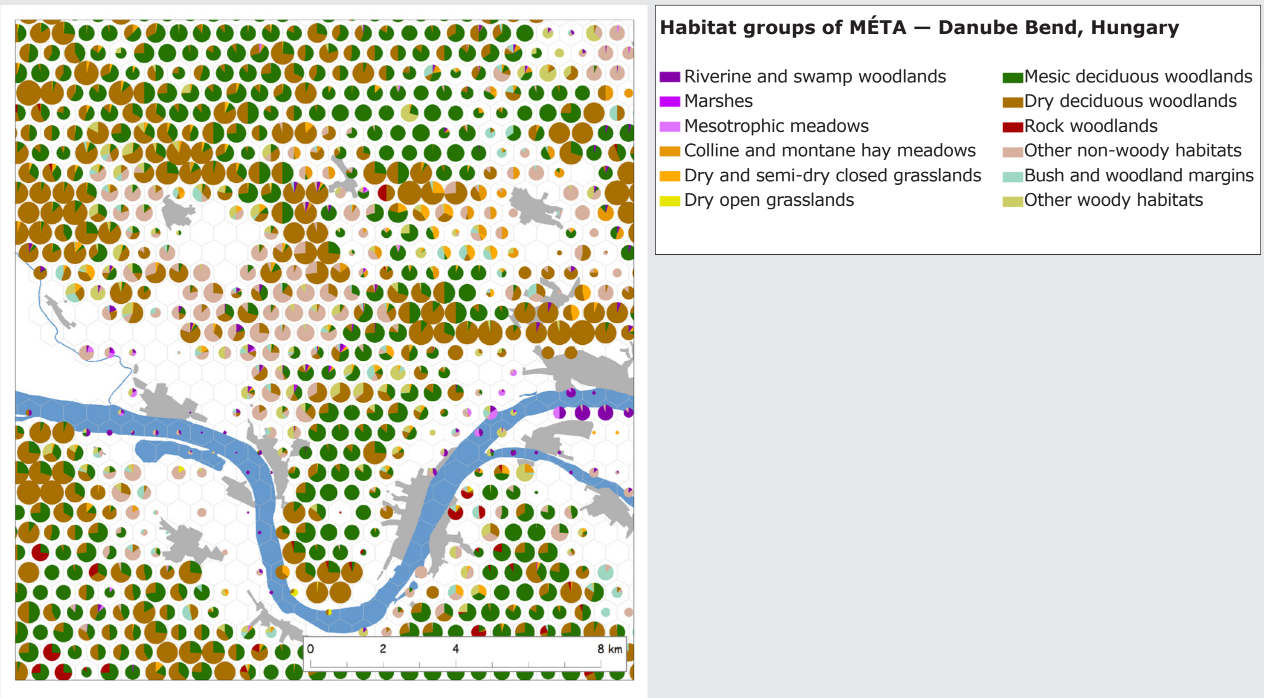
The database is often used for impact assessments, as it contains information on habitat type, habitat quality and naturalness (Bölöni et al., 2008). For general landscape evaluations, the vegetation-based natural capital index was developed (Czúcz et al., 2008). The MÉTA database was also used for the development of agri-environmental monitoring protocols (Horváth and Szitár, 2007), for predictions on the potential impacts of climate change on natural ecosystems (Czúcz et al., 2009) and to map the potential vegetation of Hungary (Somodi et al., 2009).

However, practical use of the MÉTA database for nature conservation at regional or national level is very limited. For example, the MÉTA database has not been used for the preparation of a Red List, as its habitat typology is not sufficiently detailed.

Although the database was not available at the time of the selection and designation of Natura 2000 sites, the Hungarian country report for Article 17 for the period from 2001 to 2007 was based on the MÉTA database.

Box 4.4 Case study: the MÉTA programme in Hungary (cont.)

Map 4.4 Extract of the MÉTA habitat mapping programme in Hungary



Source: MTA ÖBKI, Hungary.

Ambitious mapping schemes with insufficient planned time are likely to encounter quality issues. Several large-area mapping programmes are scheduled for less than four years. This is generally justified by budgetary constraints and political agendas. To respect deadlines there are often trade-offs between reducing the number of days in the field and increasing the number of operators (thus including less experienced surveyors). As a consequence, the general accuracy of the final map decreases.

On the other hand, programmes lasting longer than 10 to 20 years may have difficulties staying afloat. Long-term funding is scarce and several programmes risk being abandoned or delayed due to changing political agendas. Another possible problem is the risk of obsolescence and of parts of the final map being out of date by the time the project is completed.

4.4.6 Information systems

Functions and types of information systems

An information system includes all the resources required for the implementation of a computer system. It permits an optimisation of the capture, storage, manipulation, organisation and diffusion of thematic data and ensures the entire production line complies with methodological and technical constraints.

For habitat mapping, the main characteristics for the information system are the geospatial component and the typology.

As part of the survey, a review of different habitat-mapping information systems was conducted. A few key issues were highlighted: topological constraints, multiscale approaches and consistency between nomenclatures and standards, for example. The question of data acquisition tools is developed in Section 5.7.

Topological constraints

Since large-area habitat-mapping projects can involve a large number of surveyors (e.g. up to 770 in the Czech Republic), clear topological rules must be set up to ensure continuity and integrity between the different objects of the map. For instance, any change in the geometry of an object will affect its closest neighbours. Therefore the areas to be mapped are mostly subdivided as follows.

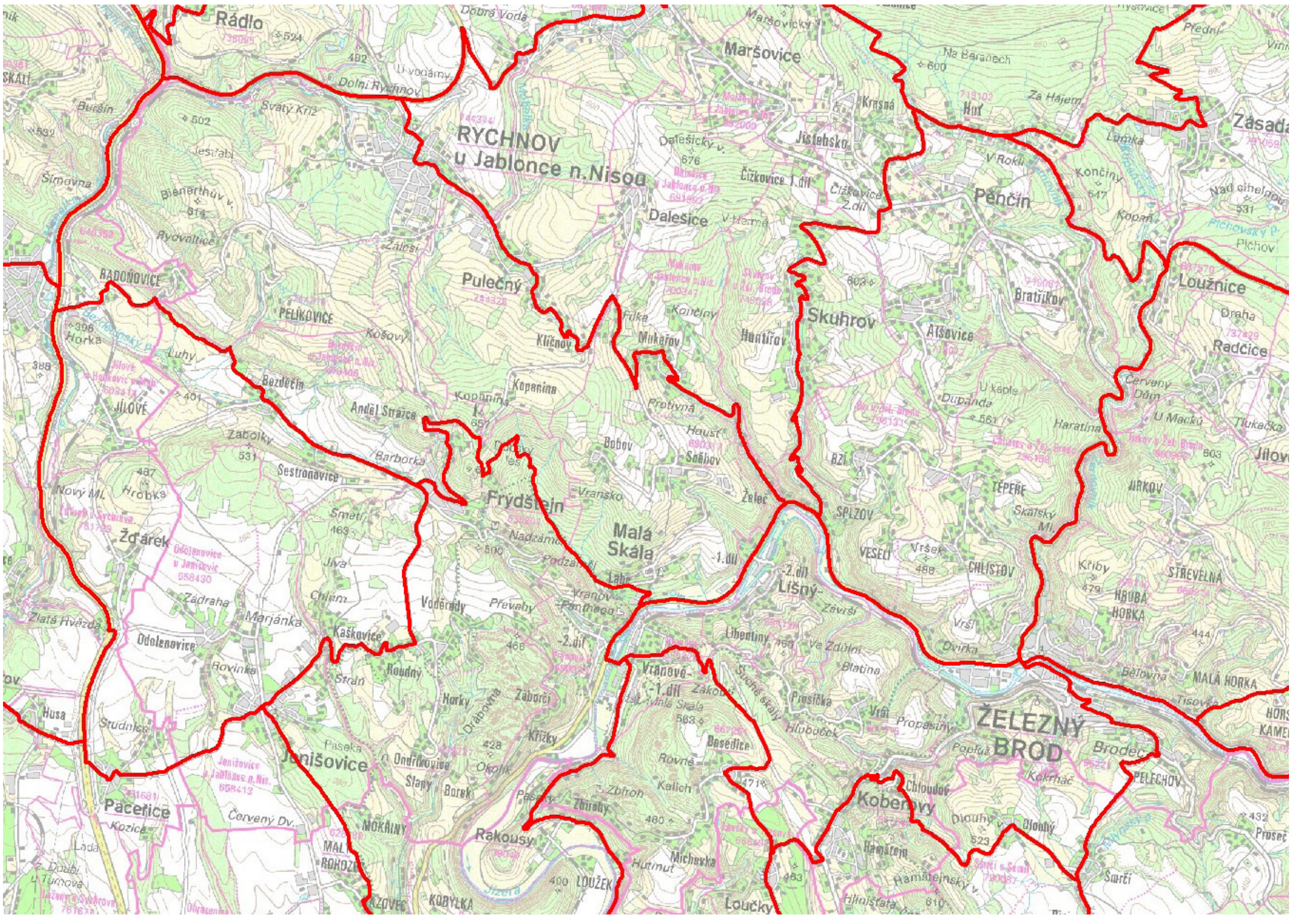
- With administrative (e.g. regions or counties) or project (e.g. mapping sheet) boundaries. Several project managers noted that joining sheets made by different authors was a time-consuming task and an important source of inconsistencies in the final product. In forest mapping in France, the Institut national de l'information géographique et forestière uses square sectors, and each sector is mapped by one operator. To ensure continuity of objects, two adjoining sectors cannot be mapped at the same time.
- With natural and/or physical boundaries of the landscape (e.g. roads, rivers). The main advantage of this approach is that those boundaries are clearly distinguishable both in the field and by remote sensing, and should not change over time, thus limiting continuity issues between objects of different sectors. This approach is successfully used by the Nature Conservation Agency of the Czech Republic (AOPK ČR) for its mapping programme (see Map 4.5).

Multiscale approach and information consistency

One of the challenges of habitat maps is that of operating at different scales in order to meet multiple needs: providing detailed information at large scale and general information at small scale.

Transition from one scale to another can be achieved by grouping similar objects together. This process, known as generalisation, must

Map 4.5 Habitat mapping districts in the Czech Republic



Source: AOPK ČR.

be organised by a set of rules, both topological (geographic) and typological (thematic). Topological generalisation corresponds to simplification of a geometric object maintaining its basic shape without causing major deformation or altering topological integrity. Thematic generalisation is a more complex issue, and cannot always be solved using higher hierarchical ranks in the classification. The vegetation cover is often organised in mosaics, and different approaches exist to represent them at smaller scale (Faliński, 1999; Pedrotti, 2004 and 2013) (see Section 4.4.5).

Consistency between typological and geographical nomenclatures and standards

The objects comprising the habitat map are attached to reference lists (geographical, typological) that are often produced according to methodological standards.

One of the roles of a nationwide or regional information system is to ensure the availability of these reference lists, their updates and their homogeneity across the area covered by the map.

The main issue lies in managing updates between the different users and data sets, since reference lists and nomenclatures frequently change. In the Czech Republic, all data are recorded online, and therefore all new data are compliant with the latest version of the reference lists.

Distributed vs centralised systems

Depending on the number and the type of partners, the objectives, and the historical and political context, information systems can be either distributed or centralised.

Box 4.5 Case study: the distributed information system of Carta della Natura in Italy

The Carta della Natura information system has two principal objectives: (i) to identify the status of the natural environment in Italy; and (ii) to assess the quality and fragility of Italian habitats. It is a basic instrument for knowledge and assessment of the Italian national territory. It is coordinated by the Italian National Institute for Environmental Protection and Research (ISPRA), a public body related to the Italian Ministry for the Environment, through a network of universities, regional administrations and regional environment agencies.

The outputs include a multiscale product: a map of the Italian Landscape Units (at a scale of 1:250 000) completed in 2001 and habitats maps at regional (1:50 000) and local (1:10 000) scales. The production of regional and local maps began in 2004, and is still ongoing, with about half of the national territory covered to date.

Habitat detection, identification and mapping are carried out by integrating information from satellite images, field surveys and other spatial data (e.g. land use or forest type maps). The experimental phase of habitat mapping only used satellite images (Landsat 7 ETM +) processed through a supervised classification type. However, physiognomic segmentation based on land use maps proved to be a much more efficient method.

The Quality Map of Ecological Value indicates natural value of the territory, and the Quality Map of Ecological Sensitivity indicates its sensitivity to degradation. Indicators involved in the production of habitat quality maps can be divided into three main groups:

- presence of habitats of natural heritage interest such as Annex I habitat types
- elements of biodiversity (presence of flora and fauna)
- elements of landscape ecology (such as patch size, shape and edge metrics).

The Quality Map of Human Impact indicates the impact of human activity as fragmentation caused by infrastructures, urban centres, industrial areas, quarries and agricultural areas. The Quality Map of Environmental Fragility is based on a combination of Environmental Sensitivity with the Human Impact, according to a double-entry matrix that highlights the most sensitive areas under the most human impact.

Data can be viewed on the Carta della Natura website (see http://sgi2.isprambiente.it/SistemaCartaNatura).

The organisation of a distributed information system is based on existing systems of the different actors involved in the mapping production. In this case, the role of the national information system is to verify consistency and interoperability between the different systems. It provides repositories and their updates and a common frame for data exchange. Data are stored in local systems, but are consolidated and assessed at a national level. In Italy, the Carta della Natura system is organised in a distributed way, with central validation occurring prior to regional diffusion (see Box 4.5).

A centralised system is based on common tools shared by all partners involved in the production of the vegetation map. It often corresponds to one national portal, resulting in higher data homogeneity, but also in more constraints for users. In this case, much emphasis should be placed on the development of tools adapted to the specific requirements of the different partners, including training. The Nature Conservation Agency of the Czech Republic is managing its biotope mapping programme with a central portal (see Box 4.6).

Interoperability with other systems

Interoperability between systems is important in order to facilitate data exchange. The objective is for different systems to access and use information from diverse sources in a consistent way. The main related international initiative is the Open Geospatial Consortium (OGC) that encourages the development and implementation of open standards for geospatial content and services, GIS data processing and data sharing (see http://www.opengeospatial.org).

In the EU, the most important development is the INSPIRE Directive that entered into force in May 2007. It establishes an infrastructure for spatial information to support Community environmental policies and policies or activities which may have an impact on the environment. Interoperability is understood as providing access to spatial data sets through network services, typically via the Internet. Specific data specifications are defined for habitats and biotopes (see http://inspire.jrc.ec.europa.eu). The habitat types from Annex I of the Habitats Directive and the EUNIS habitat classification

Box 4.6 Case study: the centralised information system of the Nature Conservation Agency of the Czech Republic

The information system used for habitat mapping in the Czech Republic is centralised, as all habitat mapping is coordinated by the Nature Conservation Agency of the Czech Republic (AOPK ČR). Field data are collected by surveyors on paper forms and printed maps. For the purpose of habitat mapping, the country is divided into 3 500 mapping districts delimited by clear landscape features (e. g. roads, railways and streams). This division facilitates orientation in the field, and the post-processing of the data.

After fieldwork is complete, surveyors submit their data in digital form through a web application (WANAS) developed and managed by the AOPK ČR. The web interface is based on two separate applications: one for tabular data, the other for spatial data. The web application is continually updated, and therefore all users work on the latest version of the application and checklists (for species names, pressures and habitats, for example), allowing more efficient post-processing. Data are first controlled by regional habitat-mapping coordinators (AOPK ČR staff) and then by the central information system manager, with help of specific control tools.

During editing, data are stored on a server as layers (lines for polygon borders and points for segment identification) and tables (biotope and species records). When a district is completed and validated, the data are transferred from a server to the central information system and polygons are automatically created with the related tables. Once a year, the information system manager consolidates a new version of the habitat mapping layer. The habitat layer combines updated data with original data from the first habitat mapping. The current version of the updated habitat-mapping layer is available for public viewing in an adjusted form on the AOPK ČR map server (see http://mapy.nature.cz). A full version is available under licence from AOPK ČR.

Box 4.7 Case study: SynBioSys

An important initiative in terms of biodiversity information systems is the Syntaxonomic Biological System (SynBioSys), a concept first developed in the Netherlands. The Dutch system (SynBioSys Netherlands) has been serving as an example for the development of a European system called SynBioSys Europe (Ozinga and Schaminée, 2004; Schaminée and Hennekens, 2001 and 2005) as well as for systems elsewhere, such as SynBioSys Fynbos that covers the rich biodiversity of the South African fynbos biome (Schaminée and Hennekens, 2011).

SynBioSys Europe is an initiative of the EVS (see Box 3.1). For the individual levels of this information system, specific sources are available (e.g. national and regional TURBOVEG databases (Hennekens and Schaminée, 2001; Schaminée et al., 2009)) for the community level, whereas data from the European Map of Natural Vegetation serve as the landscape level (Bohn et al., 2004). The structure of the system and its underlying databases allow user-defined queries. Partners will be able to upload data like vegetation relevés, and access wider views of relationships between such data and information from elsewhere in Europe through queries, analyses and visualisations.

have been adopted as the principal reference lists, and to be INSPIRE-compliant, all habitat features must have one or two habitat type encodings, an obligatory code using either Annex I or the 'EUNIS habitat classification' and an optional second code from a national or local habitat classification system, as long as they are well accepted, registered and documented.

4.4.7 *Diffusion of the results*

Rapid developments in computing and the increasing availability of large data sets open new perspectives for the diffusion of information. For example, web-based map services have now become widespread, allowing instant and interactive access to spatial data for many users. This technical evolution accompanies developments in policy promoting the accessibility of environmental data (e.g. the INSPIRE Directive and Aarhus Convention). More than 20 web GISs were encountered during the survey. They have variable levels of information and resolution, with the most basic offering a map display at a resolution equivalent to the published scale (e.g. 1:25 000). But often habitat maps can be displayed together with topographic and other thematic maps, either environmental (e.g. land use, geology, soil, and water regime) or administrative (e.g. administrative boundaries and protected areas). Some, as in Catalonia (Spain), allow free download of the mapping layer, while others require licences for the diffusion of the layers.

4.5 Key references

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5 The survey on habitat mapping initiatives in Europe: a focus on mapping methodologies

Chapter 5 summary

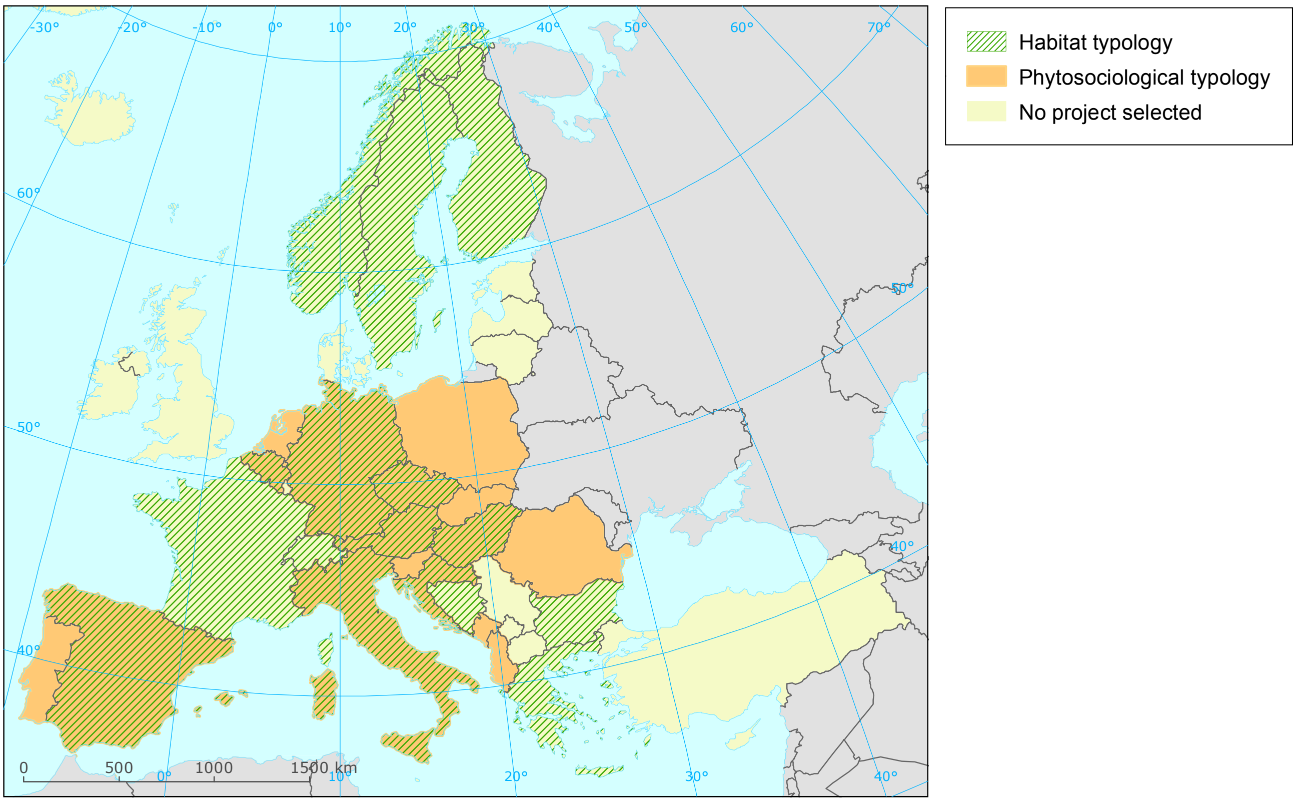
One of the main objectives of the survey was to provide relevant information for regional or national mapping projects. Therefore, special attention was paid to mapping methodologies. This chapter highlights specific issues related to typologies, mapping layers and environmental data, inventory and assessment of existing habitat maps, habitat mosaics and mapping of complexes, remote sensing and habitat modelling, field implementation, updating maps, data validation and quality control.

5.1 Different typologies for different objectives

As previously mentioned, only projects using classifications based on phytosociology or habitats/biotopes (with correspondence to phytosociology) were selected for the survey. Maps based on habitats classifications with no correspondence to phytosociology or of land cover types were not considered in any detail.

Map 5.1 shows the variability of approaches in typologies used across European countries.

Map 5.1 Typologies used by selected habitat-mapping projects in Europe



Source: MNHN, ETC/DB.

Box 5.1 Case study: preparing a vegetation/habitat classification for Greece

Vegetation sampling does not have a long tradition in Greece; therefore, there was little detailed knowledge of the majority of vegetation units and habitat types of Annex I when the Habitats Directive came into force. This led to an extensive habitat-mapping project (vegetation and habitat types, based on the Braun-Blanquet approach) being carried out from 1999 to 2001, within the tentative boundaries of the Sites of Community Importance (SCIs) of Greece (22 % of the national territory). This large, coordinated effort by Greek scientists in collaboration with foreign colleagues and funded by EU Cohesion Funds and the Greek Ministry of Environment, led to the sampling of more than 13 500 non-overlapping plots. The vegetation relevés taken within each site were used to identify and describe the vegetation communities, and thus to document the presence, extent and spatial distribution of Annex I habitat types present in Greece (85), as well as a number of habitat types considered of Greek importance (30) and corresponding to the distinguished vegetation syntaxa (Dimopoulos et al., 2006). The classification scheme used for habitat mapping in Greece contains all habitat types (of European and of Greek importance) which could be defined through vegetation types.

Classification of the vegetation relevés was performed only at local level (per site) and the derived local communities were assigned to high-rank phytosociological syntaxa (i.e. alliance, order and class). A nationwide overview of the vegetation syntaxa is still missing, since no real syntaxonomic overview exists for any part of Greece to date. The syntaxonomic scheme established in 2001 has been derived top-down, by integrating validly published orders and alliances in a successive approximation, consisting of 50 Classes, 94 Orders and 134 Alliances. The recorded habitat types correspond to 680 syntaxonomic units (mainly at community and association level, and to a lesser extent, at alliance level), which were adapted to a unified hierarchical classification system. The first syntaxonomic typology of the distinguished communities following the standard nomenclatural rules was established in 2000, and was included in the *Technical guide for the identification, description and mapping of the habitat types of Greece* (Dafis et al., 2001). The system, established in 2001, consisted of: i) the newly distinguished communities; ii) a compilation of all published associations/communities and their assignation to high-rank syntaxa (i.e. alliance, order and class); iii) a crosswalk with the Annex I habitat-types system.

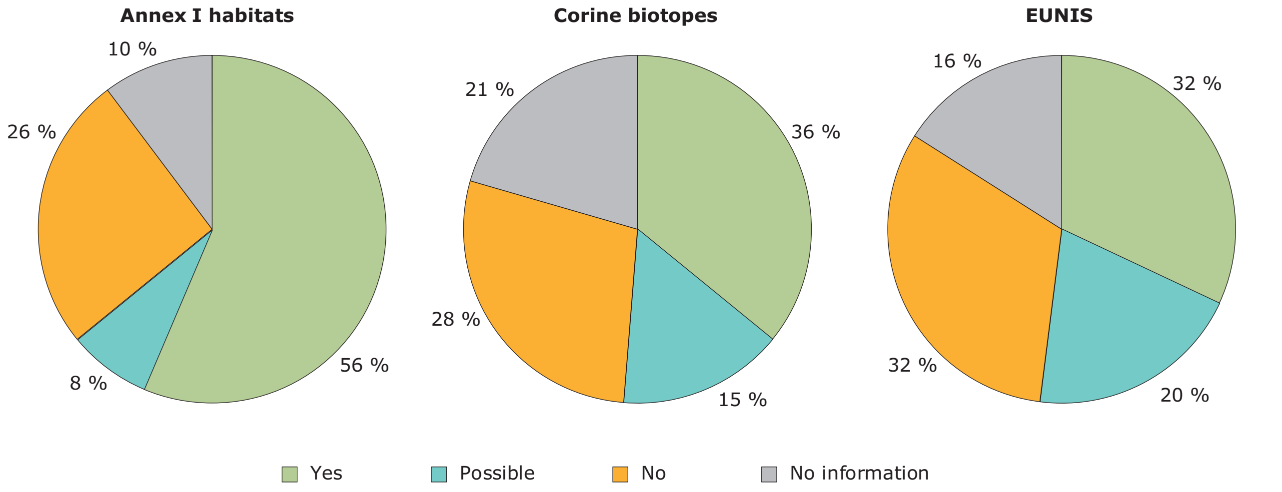
At present, work is under way to provide an overview of all the vegetation types and corresponding syntaxa occurring in Greece on the basis of relevé documentation; the aim is to produce a detailed and consistent national vegetation classification and a subsequent updated syntaxonomic scheme of the vegetation of Greece. This work will follow the nomenclatural principles adopted in the forthcoming European Vegetation Checklist (Mucina et al., in prep.).

In the majority of selected initiatives, crosswalks are set up to establish correspondences between typologies (Figure 5.1):

- 64 % of the projects completed after 1991 established a typology with a correspondence to Annex I habitats (56 % directly and 8 % indirectly);
- 51 % of the projects completed after 1991 established a typology with a correspondence to Corine biotopes (36 % directly and 15 % indirectly);
- 52 % of the projects completed after 2004 established a correspondence with EUNIS (32 % directly and 20 % indirectly).

Ensuring data interoperability is a crucial issue (see Section 3.3) (see Evans, 2006; and Ewald, 2003).

Figure 5.1 Correspondences of project-developed typologies to European typologies



Note: For Annex I habitats and Corine Biotope projects selected were completed after 1991 (n = 39); for EUNIS, projects selected were completed after 2004 (n = 25)

Box 5.2 Case study: an example of a national typology in the Czech biotope catalogue

Katalog biotopů České republiky (*The Habitat Catalogue of the Czech Republic*) is a handbook describing the habitat classification scheme used for habitat mapping in the Czech Republic. It contains all the habitat types present in the country which can be defined through vegetation types, plus two additional non-vegetated habitat types which are of interest for nature conservation. The habitat types system used in the catalogue was designed to reflect the diversity of vegetation types in the country as described in phytosociological studies, and also to be compatible with the habitat types of Community interest as defined in Annex I of the Habitats Directive and with natural habitats included in the Emerald Network.

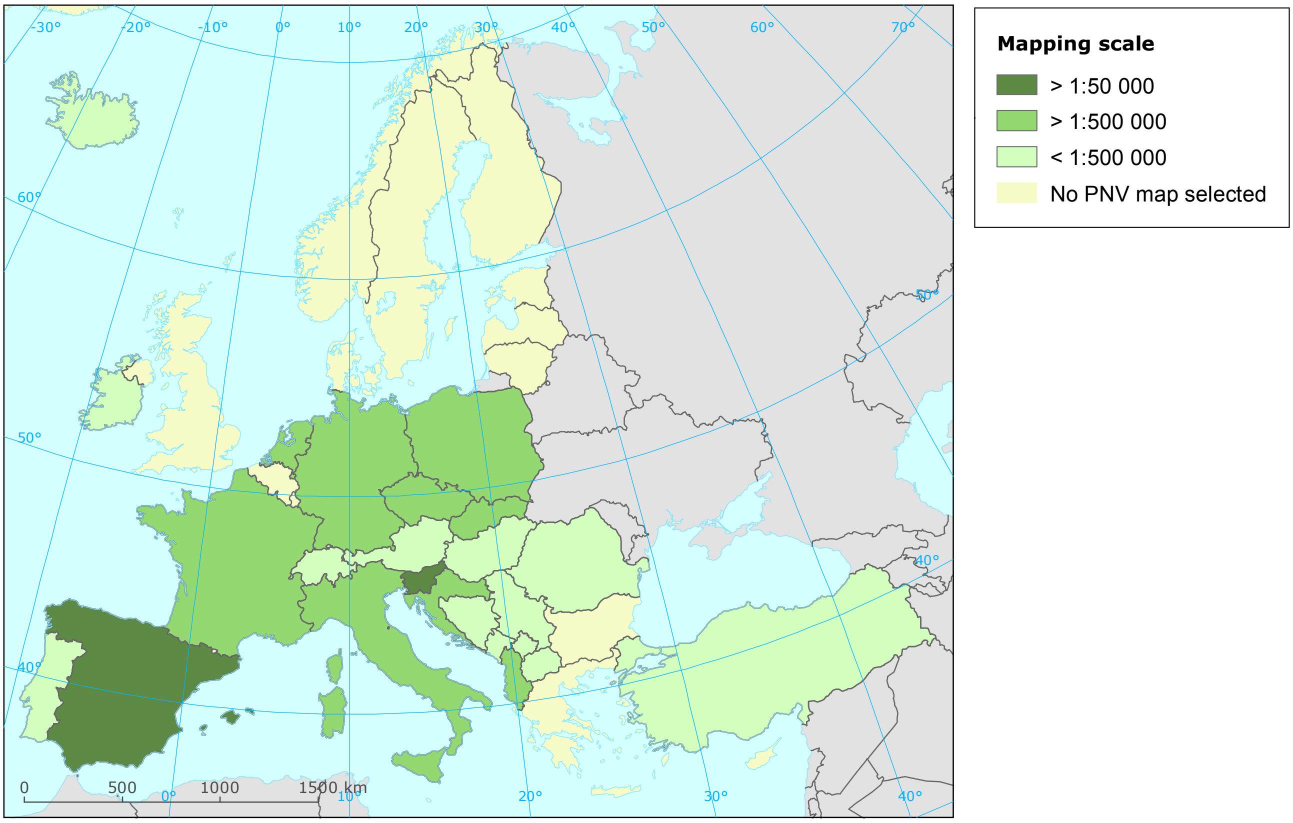
The first edition of the *Habitat Catalogue* was published in 2001 (Chytrý et al., 2001). After its publication, an extensive habitat-mapping programme was carried out in the Czech Republic, as described in Section 4.3. Habitat mapping has significantly improved knowledge of the distribution and conservation status of individual habitats in the country. This new knowledge, as well as the parallel improvements of the national vegetation classification system (Chytrý, 2007–2011) and changes in the European habitat classification were summarised in an extensively updated second edition of the *Habitat Catalogue* (Chytrý et al., 2010).

The Habitat Catalogue of the Czech Republic sets out nine habitat groups: (V) Streams and water bodies, (M) Wetlands and riverine vegetation, (R) Springs and mires, (S) Cliffs and boulder screes, (A) Alpine treeless habitats, (T) Secondary grasslands and heathlands, (K) Scrub, (L) Forests, and (X) Habitats strongly influenced or created by man. Each habitat group is divided into habitat types, some of which are subdivided into subtypes. There are 140 undivided types or subtypes, which are used as basic mapping units. To ensure compatibility with Annex I of the Habitats Directive and habitat types used in the Emerald Network, additional subtypes at the lowest hierarchical level are used in some cases. For each habitat type or subtype, a list of corresponding habitat types in European and other national systems is given, followed by description of vegetation structure and species composition, ecology, distribution, threats and management, a list of dominant, diagnostic and other frequently occurring plant species and references to major literature. For each habitat subtype or undivided type there is a distribution map in the country, based on the results of field mapping from the period spanning 2001 to 2008, with some additions based on recent relevés from the Czech National Phytosociological Database. Habitats of group X are described only briefly, as they are not the focus of nature conservation, although they are necessary for comprehensive site description.

5.2 Potential natural vegetation and vegetation series

Up to 45 potential natural vegetation (PNV) maps were identified in 24 European countries (see Map 5.2); most of them (86 %) are at landscape scale (i.e. 1:100 000 or smaller). According to our results, the only large-area PNV maps at large scale (i.e. 1:50 000) are from Spain (Basque country, Catalonia and Navarre) and Slovenia. At European level, two PNV maps exist with differing coverage, one at a 1:1 500 000 scale (Bohn & Neuhäusl, 2003) and the second at a 1:2 500 000 scale (Noirfalise, 1987); see Section 2.4.

Map 5.2 National or regional maps of PNV in Europe



Source: MNHN, ETC/DB.

Box 5.3 Case study: mapping fine-scale vegetation series in Navarra and the Basque Country, Spain

From the 1990s, some of Spain's regional administrations appreciated the utility of large-scale maps of PNV (Vegetation Series). They had experience of using the country-wide map of vegetation series map by Rivas-Martínez (1987) for nature and biodiversity conservation, particularly the targets and referential frames for defining the natural vegetation of any piece of territory, but their scale was too small for management purposes. Small regions such as Navarra (10 392 km²) and the Basque Country (7 234 km²) could afford complete mapping of their territory at a scale of 1:50 000. At first in Navarra (1988–1989) and later in the Basque Country (2002–2006), projects were undertaken using available resources with fieldwork mostly at 1:25 000, although the end-product was scaled at 1:50 000. Existing documents, such as maps of actual vegetation of particular areas, geological maps, aerial photographs and satellite images, were used to support and document the synthesis necessary to produce a map of vegetation series.

The legends and a summarised version of the map at a scale of 1:200 000 were published (Loidi and Báscones, 1995; Loidi et al., 2011) and the large-scale cartography is available via regional government websites. The legends offer a general description of the vegetation and natural conditions of the area, with chapters devoted to its geography, geology, land use history, bioclimatology and biogeography. The main text has a description of each vegetation series, with an extensive explanation of its mature stages (PNV) and most frequent forest types, as well as a description of their seral stages (e.g. grasslands and scrubs). The general environmental conditions of each series are described, with information on climate, lithology, edaphic factors and geomorphology, as well as history. The current land use and possibilities for exploitation are also described, and some conservation issues are mentioned. The document aims to be a general geobotanical description of the area, as a supporting text to the map itself, which is the main document and tool to be used by various stakeholders.

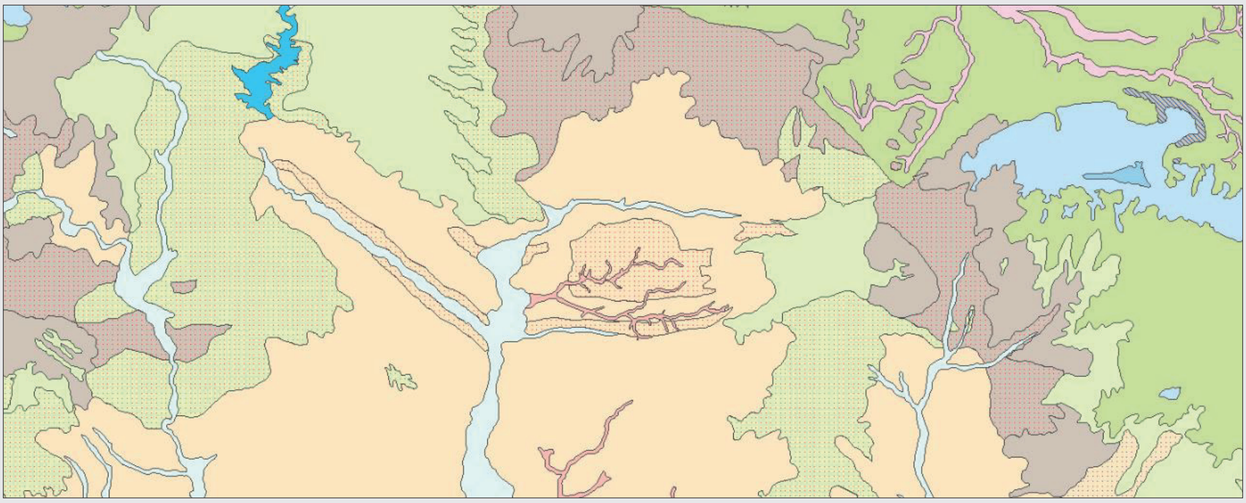
For Navarra, further work is being led by J. Peralta in the project 'Cartografía de series de vegetación y sectorización fitoclimática de Navarra a escala 1:25 000', in order to obtain a more accurate document for management purposes.

Since these maps have been made available to the general public, they have become an essential reference for any environmental study or project in the area, particularly for assessment of environmental impact and restoration projects.

For further information on Navarra, see http://idena.navarra.es/navegar/?layerid=BIODIV_Pol_SerieVe50m, and for information on the Basque Country, see http://www.geo.euskadi.net/s69-geodir/es/contenidos/informacion/recursocartografia2009/es_29/cartografia.html.

Box 5.3 Case study: mapping fine-scale vegetation series in Navarra and the Basque Country, Spain (cont.)

Map 5.3 Extract of the vegetation series map of Navarra, Spain



- 25 Castilian-Cantabrian *Quercus faginea* series
- 25a Castilian-Cantabrian *Quercus faginea* series (meso mediterranean *Quercus coccifera* facies)
- 26 Castilian-Cantabrian *Quercus rotundifolia* series
- 26b Castilian-Cantabrian *Quercus rotundifolia* series (meso mediterranean *Quercus coccifera* facies)
- 27 Lower aragonese meso mediterranean *Quercus rotundifolia* series
- 27a Lower aragonese meso mediterranean *Quercus rotundifolia* series (facies on clay)
- 33 Central Iberian meso mediterranean fluvial geoseries of white poplar
- 33 Halo-hygrophilous geoseries
- Water bodies

Note: Scale is 1:128 000.

Source: Government of Navarre, SITNA.

5.3 Base maps and environmental data

Habitat and vegetation mapping requires an in-depth knowledge of the ecological processes and biogeographical factors that influence vegetation distribution. Often, partners identify relevant and available environmental data prior to the mapping. This stage of a project is critical, because these data are potentially numerous, from varied sources and at different scales (Brzeziecki et al., 1993; Franklin, 1995). Table 5.1 lists the main environmental parameters used for habitat mapping as identified in by the survey (e.g. topographic layers, remote sensing imagery, substratum morphology and climate).

Table 5.1 The main environmental data sets used for habitat mapping in Europe

Mapping layer
Topographic layers
Topographic maps: geographic institutes, military maps
Administrative boundaries
Land registers, cadastral plans
Remote sensing (aerial and satellite imagery)
Aerial photographs and orthophotographs (i.e. geometrically corrected) including: • NIR • infrared colour aerial photographs • colour orthophotos • infrared orthophotos
Satellite images (see Section 5.5)
Ancillary data (spatially explicit environmental data)
Substratum
Geological maps
Pedological maps
Lithological maps
Morphology
Digital terrain model and digital elevation model: slope, exposure, insolation, shade, etc.
Geomorphological maps
Climate
Pluviometric map (precipitation maps)
Climate map: phytoclimatic map, thermopluviometric station network
Temperatures

Box 5.4 Case study: ecological base map for the French national habitat-mapping programme CarHAB

The University of St Etienne is responsible for developing a methodology to combine different environmental variables for the French national habitat-mapping programme CarHAB (see Section 1.2). Several options were explored including multicriteria analysis or cluster analysis, together with statistical analysis. This combination will lead to an ecological base map which will be associated with a physiognomic base map, created through remote sensing data. Data are mainly derived from three sources: elevation, climate and geology.

Many factors influencing vegetation can be derived from a digital elevation model (DEM). The first decision was which of the available DEMs to use: the shuttle radar topography mission (SRTM), the advanced spaceborne thermal emission and reflection radiometer (ASTER) or the national DEM. The first two provide elevation data on a near-global scale and are hold great interest in terms of reproducibility. However, they have a very variable precision in space. For CarHAB, it was decided to use the IGN DEM.

Climatology and geology are two fundamental parameters requiring national databases. For climate, two databases were identified, from MétéoFrance (Analysis Using the Relief for Hydrometeorology (AURELHY)) and from the ThéMA laboratory, University of Besançon (Joly et al., 2009). After analysis and comparison, both will be used for bioclimatic index calculation.

The main difficulty with geological maps results from the nature of the described information: mapping units are defined by their age, while the most important information for habitat mapping is the facies (e.g. limestone, sandstone, or basalt) which influences the soil physical and chemical properties (e.g. pH, and grain size) which are important for plants. For geology, the 1:100 M lithological map of France meets the requirements of national coverage, but scale is not suitable for a 1:25 000 vegetation map. Therefore it will be complemented by an interpretation of larger scale maps.

5.4 Inventory and assessment of existing habitat maps

Due to the diversity of habitat mapping approaches, few countries have exhaustive knowledge of all existing maps of their territory. Reviewing these approaches is often a preliminary step to nationwide habitat mapping. Countries that conducted centrally organised projects (e.g. the Czech Republic and Hungary) are exceptions to the rule. In 1994, the Austrian Federal Environment Agency produced an overview of the status of biotope mapping in Austria (Winkler, 1995). More than 1 200 maps were inventoried, 93 % of which were commissioned by local governments. Some 48 % of the Austrian municipalities were covered by a mapping project; the main objective was provisional planning for nature conservation. More recently, France conducted a similar survey to inventory and assess available habitat maps as part of the national habitat-mapping programme CarHAB (see Box 5.5).

Box 5.5 Case study: inventory and assessment of habitat mapping in France for the CarHAB programme

In 2012, the French Ministère de l'Écologie, du Développement durable et de l'Énergie (Ministry of Ecology, Sustainable Development and Energy) commissioned the Fédération des Conservatoires botaniques nationaux (Federation of National Botanical Conservancies) to undertake a national survey of existing habitat maps. A questionnaire was sent to each Conservatoire Botanique National (CBN) usually responsible for the collection, validation and use of vegetation data in their region. The survey revealed that more than 1 880 vegetation or habitat mapping projects were available, covering about 27 % of the natural and semi-natural terrestrial area of France.

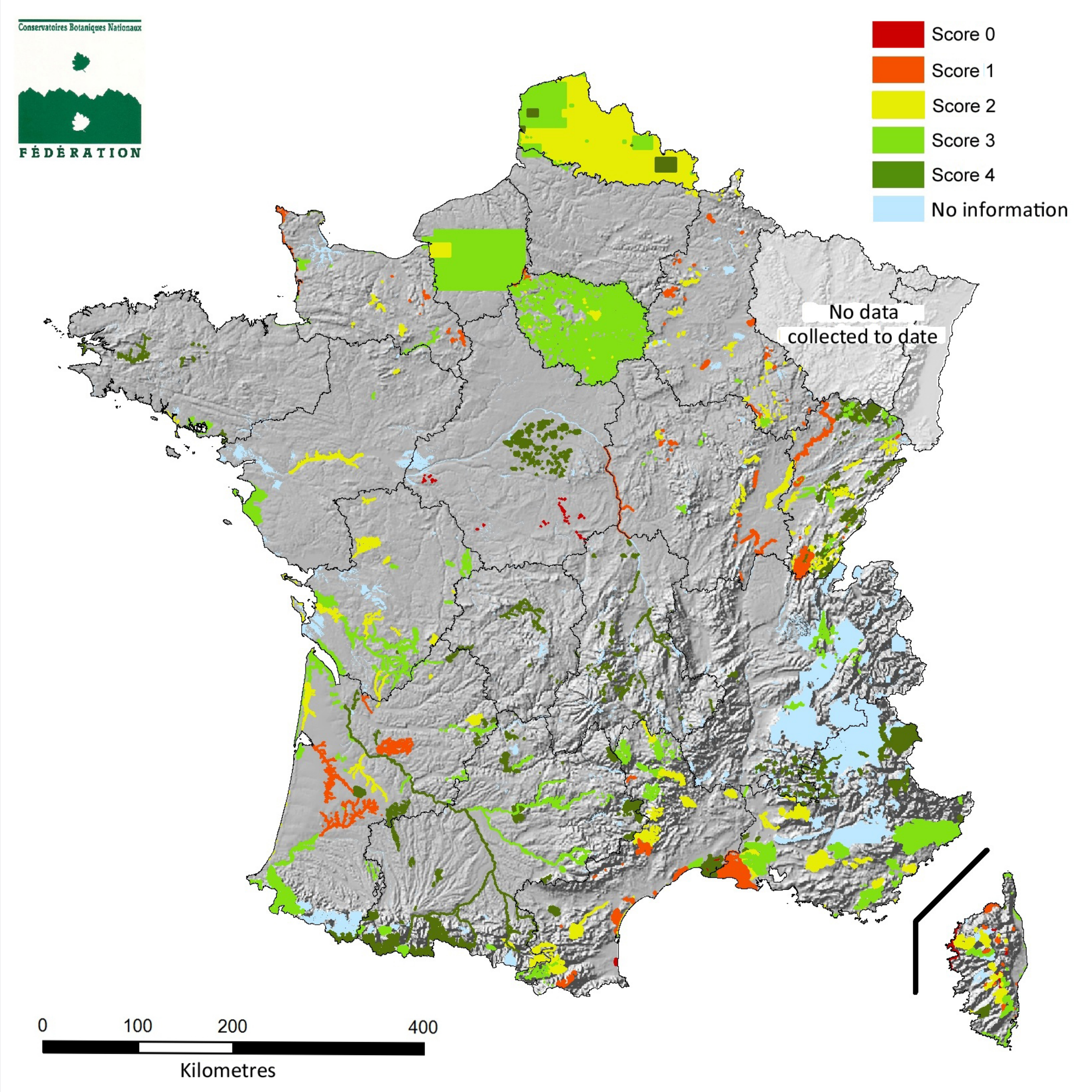
As there are many different approaches to vegetation mapping, the survey assessed the description of map parameters and map quality. In the resulting report, for each criterion, thresholds were proposed in order to assess the quality of each map. A map showing this evaluation was produced, and it is reproduced below as Map 5.4.

The use of vegetation mapping varies across France; some regions such as Ile-de-France, Rhône-Alpes, Nord-Pas-de-Calais and Provence-Alpes-Côte d'Azur have historically produced more maps than elsewhere. An equal number of maps were produced using habitat and phytosociological approaches. Half of the projects were considered useful for the CarHAB project. These maps could therefore be used as part of a control and correction phase.

A total of 12 maps were selected for additional analysis, on the basis of their coverage, scale, typology, and methodologies used in their production. This included a vegetation map of the Boulogne region (north-west France), a project which had inspired CarHAB, as it was the first French map at a 1:25 000 scale using a phytosociological approach over such a large area. Important maps were also produced in the Alps, offering a national perspective on vegetation mapping methodologies and including the use of photo-interpretation prior to fieldwork. These mapping projects and associated methodologies constitute a solid basis for the implementation of the CarHAB programme.

Box 5.5 Case study: inventory and assessment of habitat mapping in France for the CarHAB programme (cont.)

Map 5.4 Inventory and quality assessment of habitat mapping in France



Note: Legend: Assessment of map quality (0 = poor, 4 = very good).

Scale: 1:5 500 000; 1 882 maps inventoried on 1 December 2012 (1 195 represented).

Source: FCBN, CBNx.

5.5 Mapping of habitat mosaics and complexes

Vegetation mosaics or complexes are found when two or more communities, each occupying small areas, are found in close proximity, often as a repeating pattern. It is a constant mapping issue as scale increases (decreasing precision), because individual vegetation types can no longer be represented. The concept of vegetation complexes has been developed mainly by Schmithüsen (1948) and Tüxen (1978), but many other authors have developed their own concepts.

According to dynamic and landscape approaches to vegetation science, the distribution of plant associations within homogeneous regions is not random, and there is a tendency of associations to be related. These relationships can be divided into two categories (Géhu, 2006; Pignatti, 1995):), as shown below.

- Temporal (i.e. dynamic): communities substitute for each other over time, starting with a pioneer stage and evolving towards a climax community.
- Spatial, as a result of topographical factors, i.e. micromorphology of the substratum or the soil. They can be open or closed, depending on whether the mosaic elements are separated by substrate. An example is a bog system where hummocks and hollows can be shown on a large-scale map, but not at smaller scales.

In terms of mapping complexes or mosaics, several approaches (Härtel, Lončáková and Hošek, 2009; Pedrotti, 2004; Pignatti, 1995; Smith, O'Donoghue, O'Hora and Delaney, 2011) were found to be used.

One approach includes mosaics as a mapping unit in the typology (cartographic mosaic), considering that mosaics patterns repeat within a homogeneous area. The composite habitat types are noted in the legend. For example, on the vegetation map of the Danube Delta Biosphere Reserve in Romania, 43 vegetation units have been mapped, and each vegetation unit represents a mosaic of several associations (Hanganu et al., 2002).

Another approach applies mapping of the mosaics as the sum of the different component associations. Traditionally, two vegetation types occurring together as a mosaic are represented with alternating stripes of different colours. An example is the natural vegetation map of the lagoon Valli di Comacchio in Italy (Ferrari et al., 1972). Nowadays, with the development of GISs, one polygon on a map can be attributed to many individual habitats. In most cases, only habitats with a minimum coverage (e.g. 25 %) are recorded, and it is often limited to the 2 to 4 most dominant habitats (e.g. the Czech Republic, Norway and Slovenia).

A third approach is aggregating patches of the same type in order to form a bigger polygon, without representing the mosaic on the map. In the Italian project Carta della Natura (Angelini et al., 2009), all the patches of the same habitat type that were separated by a distance less than a distance related to the patch size were merged, including the matrix portion that separates them. Thus, a polygon was obtained with a surface area equal to or higher than the minimum mapping unit. When this is not possible, because the patches are too distant or the surface of the aggregation is too small, the polygon is attributed to the predominant habitat types.

A fourth approach, used for maps based on dynamic landscape phytosociology, groups all the associations belonging to the same vegetation series into one ecologically homogeneous unit known as a tessela (small square or piece of mosaic in Latin). One tessela reflects the same meso-climate, type of soil and geomorphology (see Section 2.2) (Rivas-Martínez, 2005). Nonetheless, a tessela is not necessarily spatially homogeneous. In the case of azonal soils, edaphic factors induce different vegetation series (edaphophilous series) within the same meso-climate. This generates complexes of series with the same problems in terms of representation on a map. However, at landscape level it is possible to identify repetitive patterns known as geoseries delimited within a biogeographical unit.

Photo 5.1 Mapping of habitat mosaics in Brittany, France
© A. Lieurade

Figure 5.2 Changes in the number of projects using satellite imagery over time

Note: This figure is based on all projects where the information was available (56 projects out of 159) and not limited to the selected projects.

5.6 Remote sensing and habitat modelling

5.6.1 *Remote sensing*

In vegetation mapping, remote sensing refers to the techniques that allow acquisition of information about the Earth's surface in order to discriminate different types of habitats or vegetation (see Section 3.4.1). Manual interpretation of aerial photography is the traditional approach, but more advanced technologies, including automated image interpretation and satellite imagery, are now in wide use. Satellite imagery for large-area vegetation mapping has been used since the end of the 1980s, and its use has increased since the end of the 1990s. However, only a quarter (26 %) of all projects identified in the survey (not only those selected) used satellite imagery, while 12 % used additional treatments and analyses such as (semi-)automatic segmentation and/or classification. The most frequently used satellite-based products are SPOT (38 %), Landsat (31 %), Corine Land Cover (13 %), ASTER (6 %), IKONOS (6 %) and IRS (6 %).

5.6.2 *Habitat modelling*

Habitat modelling is the prediction of habitat distribution based on spatially explicit environmental data (see Section 3.4.2). Few of the selected mapping projects included habitat modelling in their work, and therefore we enlarged our analysis to include all projects (n = 163). We found 17 programmes starting from 1989 (Environmental Thematic Cartography of Asturias, Spain) with an increase at the end of the 1990s corresponding to 28 % of the programmes where the information was available (n = 60). A majority (59 %) concerned areas smaller than 50 000 km².

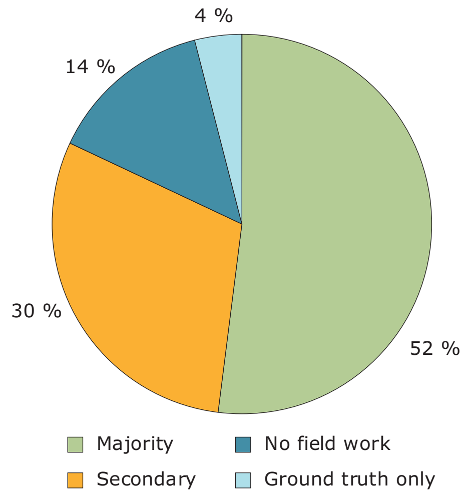
5.7 Field implementation

5.7.1 *Human resources*

More than half of the projects inventoried were predominantly based on field surveys. For 30 % of the responses obtained, fieldwork was secondary and combined with other approaches such as remote sensing and/or modelling. In other cases (4 %), fieldwork was limited to validation (ground truthing). Finally, some maps (14 %) are produced using only existing information (maps and data sets).

Habitat mapping requires considerable skills, mainly in botany and cartography, often supported by photo-interpretation. The number of field surveyors involved is very variable, ranging from 5 (for the map of the vegetation series of the Basque Country) to 770 (for the habitat map of the Czech Republic). Questions of heterogeneity of perception, training and the role of interpretation documents and decision rules are discussed in Section 5.9.

Figure 5.3 Use of fieldwork for large-area mapping programmes



5.7.2 Field devices

Handheld devices are field computers allowing the use of a GIS with accurate positioning. They have developed thanks to the improvement of mobile technologies (e.g. pocket PCs, tablet computers, personal digital assistants, and rugged laptops). For biological surveys, they are increasingly used for field-data acquisition across large areas such as plot surveys and inventories. However their use remains limited for habitat mapping. Some pilot projects using mobile technologies were identified, and their experience was used to highlight potential and current limits. They include the Forestry Commission in the United Kingdom, the Český kras Natural Park in the Czech Republic, the Office National des Forêts in France (Natura 2000 sites) and the future nationwide habitat-mapping project for France, CarHAB (see Section 1.2).

One of the main advantages of such tools is saving time spent on data entry. In traditional mapping, information is collected on paper (e.g. notepads and maps), and additional time after fieldwork is required for data transfer. Mobile devices also allow automatic updates on a central database, and when a connection is available (e.g. GSM or 3G), synchronisation can be performed in real time. Direct entry can also reduce transcription errors.

Surveyors report many advantages of such devices: besides aiding navigation, relevant information can be easily consulted in the field, for example maps (e.g. topography geology), data sets (e.g. species occurrence) and diagnostic tools (e.g. determination keys or interpretation manuals). However, additional preparation time is required prior to field survey for configuration of the tools. Interfaces need to be adapted to the mapping methodology, the scientific protocols and the type of data to be collected.

In spite of continuous technological improvements, several difficulties remain. Size, weight, autonomy (battery life), fragility and display quality (e.g. many screens are difficult to use in direct sunlight) are all potential limitations. Another aspect is the difficulty some field surveyors have in accepting such tools and the resulting change in data flow. Training and adaptability of the tool are key points.

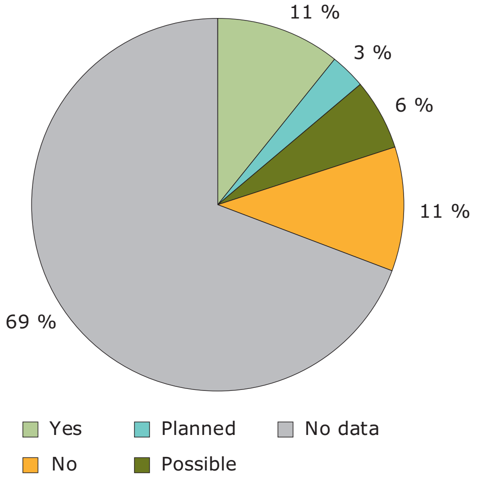
Photo 5.2 Field devices in the Český kras Natural Park in the Czech Republic © J. Ichter

5.8 Updating maps

All maps and associated databases become outdated (although they remain valuable as a historical record), and require revision if they are to continue to be used. Our results highlight that updating maps is a difficult issue and only 14 % of the selected projects have been or will be updated. In most cases, no information on updating was reported (69 %).

Updates can be either complete (i.e. revising the entire map of a given area) or partial (i.e. segment by segment, sometimes focusing on regions known to have changed, such as burned areas). The best approach would be to repeat the original survey, using the same methodology, people, timing, information system, etc., and preferably it should be planned in advance. However, this is rarely, if ever, possible; 11 % of the selected projects do not consider it possible.

Figure 5.4 Updating of large-area habitat map information



Box 5.6 Case study: updating the biotope map of the Czech Republic

The Czech biotope mapping project covers the entire country using a specially developed biotope classification (see case studies in Section 4.4.5 and Section 5.1 for details). The first map was published in 2004; revision started in 2006 and has continued ever since, involving 100 to 150 botanists each year, surveying at a scale of 1:10 000.

Photo 5.3 Updating the biotope map of the Czech Republic
© J. Ichter

Not all the data required for reporting under Article 17 of the Habitats Directive proved to be available directly from the original mapping layer; it transpired that obtaining many of the data was problematic. Information on areas was available in excellent detail, and information on pressures and threats was, to a certain extent, also available. Problems appeared with the direct transformation of the field data for representativeness and conservation status into the required assessment of structure and function, and the assessment of habitat degradation. The methodology for the mapping update was adjusted in order to solve these problems. The resurvey also focuses more on the quality characteristics (assessment of degradation, structure and functions of individual habitats) and on collecting data about occurrence of typical plant species, which proved to be a very useful source of information. Detailed information on plant species collected during the second habitat mapping also provides information for Article 17 reporting for many plant species (e.g. *Arnica montana* and *Leucobryum glaucum*). The project aims to update the entire habitat-mapping layer every 12 years. This period was set in order to follow the six-year reporting period under Article 17. Thus for every reporting period, there will be new habitat data from one half of the country, supplemented with the old data from the rest of the area.

5.9 Data validation and quality control

Of the selected projects, 23 % reported that quality was assessed. However, habitat and vegetation maps resulting from field surveys almost always lack information on accuracy or validation procedures. Field surveyors tend to attribute high quality to their products, although they are rarely tested. However, experiments show that large differences between surveyors are found. Cherrill and McClean (1999a and 1999b), Hearn et al. (2011) and Stevens et al. (2004) observed that spatial errors occur, but that the majority of differences between surveyors are due to classification errors.

In general, map quality benefits from using well-trained field surveyors. Experience can reduce observer variation and provide acceptable levels of consistency (Souter et al., 2010; Kelly et al., 2011; Hearn et al., 2011). Stevens et al. (2004) found that results were considerably better within a carefully coordinated team from one organisation than those reported by studies of consistency between organisations. Regular joint fieldwork helps achieve standardisation; test cases with dual mapping and cross-checking can detect and adjust differences in approaches and interpretations. Such a framework is of key significance. This is certainly the case if the mapping project is part of a monitoring programme, since repeatability is of utmost importance.

5.9.1 *Topographical accuracy*

The available base maps or aerial photographs are of major importance, and well-interpreted base maps reduce the risk of not visiting clearly different habitat patches, or hidden corners and delineation of map polygons is much more accurate.

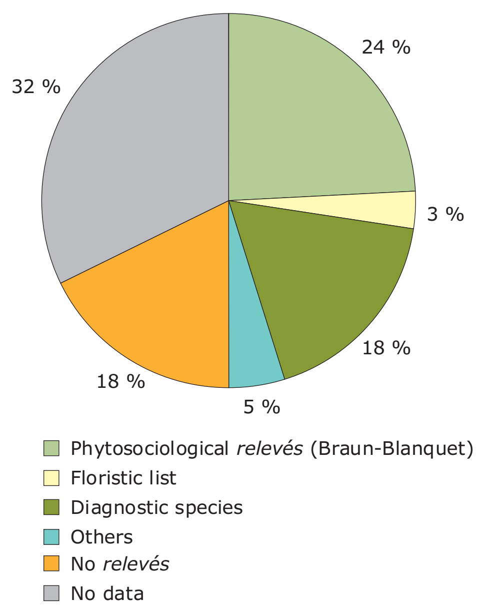
Explicit decision rules are needed for a standardised and repeatable delineation of polygons. The lack of such rules often renders the map polygons useless for statistics, comparisons of time series, etc. In parcelled landscapes, the parcel may be the primary mapping unit. But, depending on the goal of the survey, even parcels can be heterogeneous and may need to be divided. Moreover, unparcelled landscapes dominate many (semi-)natural areas. Gradients and vague boundaries (ecotones, and above all ecoclines) are frequently encountered and difficult to deal with. The European BioHab/EBONE approach provides a recommended set of mapping rules (see Section 3.2 and Section 6.1.1). Using its basic rules and a selection of useful elements could contribute to higher levels of repeatability.

Hearn et al. (2011) indicate that boundary errors can be reduced by preprocessing (e.g. remote sensing) or through the use of methods which include spatial analysis to detect and quantify spatial pattern at ecotones/ecoclines, alongside statistics and modelling (Gosz, 1993; Kent et al., 1997; Fortin et al., 2000). They also indicate the importance of mapping scale as a reason for differences between surveyors. Standardisation requires standard protocols (scale and resolution of mapping, base map, minimum survey effort, etc.).

5.9.2 *Typological accuracy*

Half of the selected projects systematically collect data on species composition by recording *relevés* to ensure that polygons are correctly assigned to the appropriate habitat or plant community. A quarter of the projects record phytosociological *relevés*, i.e. a complete list of species for each plot combine with an estimation of the species coverage. However this greatly increases the time required for fieldwork. Standardisation of data collection (see Section 5.9.3) can greatly improve the typological accuracy of any survey.

Figure 5.5 Type of floristic data collected for habitat mapping programmes



5.9.3 *Standardisation*

A mapping programme based on direct habitat/vegetation interpretation in the field may be standardised in the following ways.

- Using a predefined and fixed set of legend units. Such an approach requires thorough preparation, but it is of the utmost importance in order to achieve an acceptable level of comparability in space and time. An example of such an approach is the Biological Valuation Map of Belgium (De Blust et al., 1985; De Blust et al., 1994; Vriens et al., 2011) (see http://www.inbo.be/bvm).

- Clarity in definitions: the more precisely the limits of a legend unit are defined, the more uniform its use will be. A true determination key with a high level of floristic information and easy-to-detect landscape-ecological features is advisable. An example of such a key is under construction in Flanders, Belgium (shown in Figure 5.6). It reuses existing elements and rules from BioHab/EBONE and EUNIS as a starting point, and has the advantages of the classification 'fitting' into a European approach, and being compliant with the EU INSPIRE Directive. Special attention must be paid to mosaics (Cherrill and McClean, 1999a).

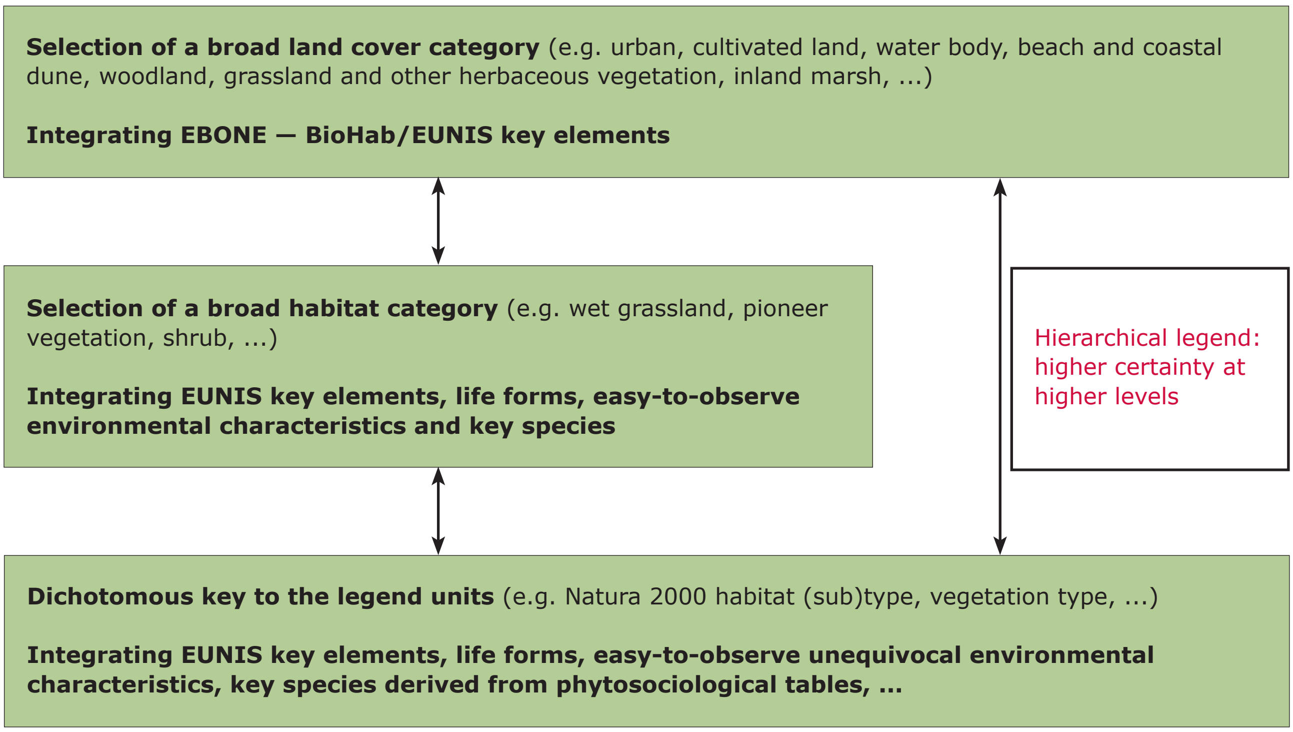
- Using a hierarchical classification system can contribute to a higher mapping accuracy. As proved by Hearn et al. (2011), in the United Kingdom, even well-trained surveyors frequently confuse communities with similar species' composition and appearance. Although this is difficult to solve (even with a determination key), a hierarchical classification system can be useful, as at higher levels, the distinction can be more explicit.

The data source of the type attributed to each map polygon is important information for the users. Such information should always be included in the GIS database, taking into account the following recommendations.

- In many mapping projects, not all delineated polygons originate from field visits. It is important to differentiate between desk interpretations of aerial photographs, extrapolations and field visits, for instance.

- The year (or actual date) of the field visit of a map polygon gives an indication of the probability that the map is still valid.

Figure 5.6 Set of rules for the development of a habitat identification key to support habitat mapping in Flanders, Belgium



- The month (or season) of the field visit can influence reliability. For example, a forest mapped in summer in a region where forest types are differentiated by spring flowers will offer an accurate interpretation of the tree layer, but a less reliable overall interpretation. This is particularly important for 'seasonal' habitats such as turloughs (seasonal lakes).

Quantitative map validation calls for statistical approaches, as illustrated by the Belgian case study in Box 5.7.

Box 5.7 Case study: validation of the Flemish Natura 2000 habitat map

Stakeholders requested validation of the Flemish habitat map (Paelinckx et al., 2009). Their main questions were 'What proportion of the area mapped as habitat x is really habitat x?' and 'How reliable is the classification?' (e.g. Are patches indicated as dune habitat really dune habitat?). In other words, how many false positives are there on the habitat map? The false negatives, i.e. existing habitat patches that are lacking from the habitat map, are not taken into consideration in this validation survey, because these were of lesser importance for the stakeholders.

For each Annex I habitat group (forests, coastal dunes, heathlands including inland dunes, mires and fens), a statistically robust sampling scheme for field testing was designed (Figure 5.7). Important issues for the design are explained below.

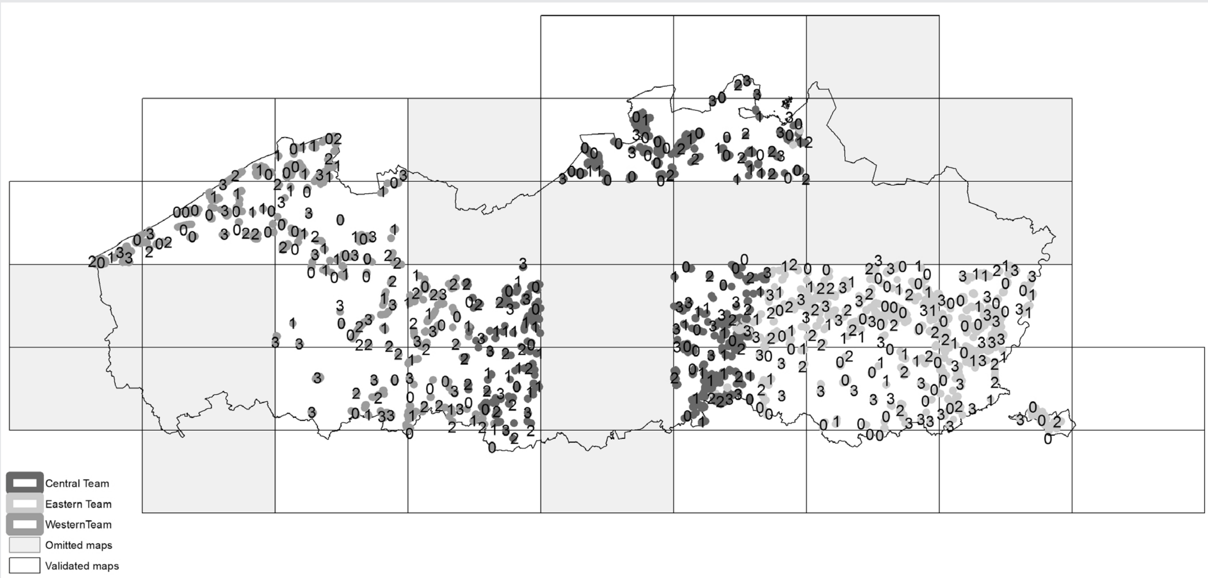
- Habitat polygons shown on the habitat map served as sampling units. Presence/absence of habitat types was recorded for the entire map unit, and delivered a true/false statement about the patch.
- The sample size was primarily a function of the sampling population (e.g. the total number of habitat patches for one habitat group). In addition, a priori estimation of the proportion of the expected 'true' versus 'false' classification has a significant effect (the sample size is maximum when this proportion is 50/50). For a confidence interval of 95 %, and a desired maximum absolute error of 5 % ('accuracy'), the theoretical sample sizes for the Flemish habitat map ranges from 30 for coastal dunes (total area of about 2 400 ha; almost no uncertainty) to 330 for heathlands (total area of about 10 000 ha; moderate uncertainty) (Onkelinx and Quataert, 2009).
- The initial questions focus on area proportions. We therefore weighted each individual polygon with its surface area in the random selection procedure.
- Fieldwork was optimised by spatially grouping sampling locations into three areas (Figure 5.7). We also provided four randomly selected subsets, to allow for interim calculation of representative results (albeit with lower accuracy). As Figure 5.8 shows, the theoretical samples sizes were not carried out in full, due to time constraints. This is one of the reasons for accuracy intervals much larger than 5 %.

Figure 5.8 shows that differences between the habitat groups are apparent. Besides the already-mentioned too small sample sizes, this is due to the following.

- For forests, false positives are not expected, because all native deciduous forests in the survey area belong to forest habitat.
- Important reasons for false positives of the other habitat groups include recent succession (fieldwork 2000–2009; validation fieldwork 2010) and lack of uniformity regarding the lower limits of the habitat types. For mires and fens, it is plausible that lower accuracy arises from relatively high uncertainties (25 % of the total surface area) associated with translation of the original map legend (= the biological valuation map) to Natura 2000 habitat types.

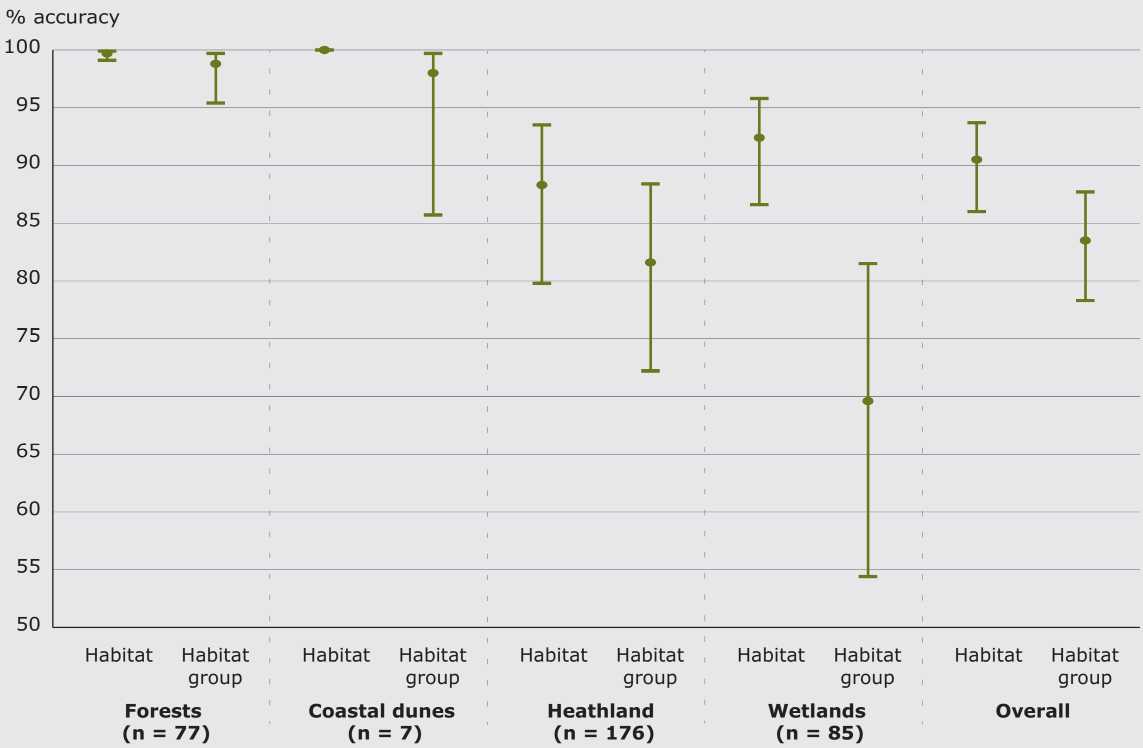
Box 5.7 Case study: validation of the Flemish Natura 2000 habitat map (cont.)

Figure 5.7 Sample design for all habitat groups: spatial grouping of samples for fieldwork



Note: Habitat maps completed before 2000 are omitted; three field teams; and random subsampling for interim results (four sets: 0, 1, 2, and 3).

Figure 5.8 Confidence intervals for overall accuracy of the habitat map and for some habitat groups in particular



Note: Accuracies were calculated for presence of habitat (Habitat) and presence of habitat belonging to the correct habitat group (Group).

Confidence intervals = 95 %.

5.10 Key references

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6 Uses and applications of habitat mapping

Chapter 6 summary

Although habitat maps in Europe have been primarily used for the implementation of the EU Habitats Directive in recent years, there is also a wealth of other uses, e.g. national and local nature conservation policies, green infrastructure, agri-environmental policies, forest management and ecosystem services. Through different examples, this chapter shows that some applications are widely used, while others are still under development.

6.1 Nature conservation

6.1.1 Habitats Directive and other initiatives at European scale

Biogeographical regions

The official map of the 9 biogeographical regions mentioned in the EU Habitats Directive and the pan-European map of 11 biogeographic regions used for the Emerald Network under the Bern Convention were produced from the maps of PNV by Noirfalise et al. (1987) and Bohn et al. (2000–2003) by associating each mapping unit to a biogeographical region (as defined in the Habitats Directive for the EU) or to an azonal group. The resulting map was then generalised and in some cases modified to align the regions with national boundaries (see the ETC/BD (2006), for further details). The map was produced for implementation of European policy instruments, but has also been used for other purposes, for example as a sampling frame for the EU-funded Biopress project which studied land cover changes across Europe.

Identification of potential Natura 2000 and Emerald sites

Annex I of the Habitats Directive provides the list of habitats considered of European concern for which Member States of the EU have a responsibility to designate Natura 2000 sites (together with species listed on Annex II) and further ensure their favourable conservation status through appropriate management. Similarly, under the Bern Convention, non-EU countries which are Contracting Parties to the Convention have to designate so-called Emerald sites to ensure the protection of habitats listed under Resolution 4 (and species listed under Resolution 6) of the Convention.

In both cases, there is a need for countries to identify the most suitable sites to be designated, in order to ensure the conservation of the targeted habitats. This calls for reliable knowledge of the surface area and distribution of the targeted habitats across each country. However, only a few countries such as Spain and the Czech Republic had suitable habitat maps of their territory prior to the identification of Natura 2000 sites. As shown in the results of the survey (Chapter 4), many countries have consistently mapped Annex I habitats only within Natura 2000 sites once those had been selected for designation on the basis of other pre-existing information.

Reporting on habitat types within Natura 2000 sites

Member States are required to describe each Natura 2000 site using an agreed 'Standard Data Form', and for sites which include one or more Annex I habitat types, information is needed on the area of each habitat type within the site, together with assessments of quality and importance. The most important information requirements for habitats are the following.

- The area of each habitat type present on each site must be given in hectares (in the past, this was given as a percentage of the site area).

Box 6.1 Case study: inventory of habitats of Annex I — EU Habitats Directive in Spain

A national project led by the Spanish Institute for Nature Conservation (ICONA), with the help of a coordination group, was launched in 1999 to map Annex I habitats prior to the identification of potential Natura 2000 sites. Initially, a Spanish interpretation manual for Annex I habitats was prepared by Prof. S. Rivas-Martínez. This manual describes the Annex I habitats as found in Spain and set out the units to be mapped.

Some 250 specialists affiliated with more than 30 institutes and research centres distributed across the country were involved in the surveying, with scientific coordination by Prof. Rivas-Martínez. The group comprised mostly botanists and phytosociologists, but also included other specialists. The aim was to inventory the habitat types on 1:50 000 scale topographic maps and fieldwork started in 1994 and lasted till the end of 1996 when the 1 114 sheets (equivalent to 960 full sheets) were delivered to ICONA. This procedure assured an accurate inventory of all the habitat types for each of the four biogeographical regions present in Spain. The project was financed by LIFE (Loidi, 1999).

- The degree of representativity expresses the similarity between the habitat occurrences in the site and the description of a typical habitat occurrence given in the European *Interpretation Manual* (EC, 2013). It is scored as one of four categories: 'excellent', 'good', 'significant', or 'non-significant presence'. It can be assessed by comparing current species composition of the habitat with a typical species composition of the habitat. Vegetation relevés are an obvious means of collecting data, and analyses can be supported by software programmes like SynBioSys (Schaminée et al., 2007).

- The relative surface of a habitat is the area of the site covered by that habitat type in relation to the total area covered by the same habitat type within the national territory. Consequently, this requires that both the area in the site and the nationwide area of the habitat be known. Large-area mapping or extensive point sampling methods can be used to obtain these figures. As the total area is often an estimation, relative surface is reported using three classes (0–2, 2–15, and 15–100 %), rather than an exact figure.

- The degree of conservation expresses to what degree structures and functions of the habitat have been conserved on the site, and whether restoration is possible. Each of these three aspects (structures, functions and restoration possibilities) is scored separately (three score levels each) and then integrated. The final score on the degree of conservation of a habitat in a site is defined as either 'excellent', 'good' or 'average/reduced'. Despite some conceptual differences, data collection can be coupled to habitat quality monitoring at patch level (see below).

Assessment of habitat conservation status at the biogeographical scale

Article 11 of the Habitats Directive requires that 'Member States shall undertake surveillance of the conservation status of the natural habitats and species referred to in Article 2 (of the directive) with particular regard to priority natural habitat types and priority species'. Similarly, Article 17 calls for a report every six years on the conservation status of species and habitat types of Community Importance, and on the performance and the effects of their conservation and land use policies and management practices. This assessment is carried out per biogeographic region and, if relevant, per marine region. Thus if a habitat is present in four biogeographic regions, the Member State should report four assessments of the conservation status of this habitat, each corresponding to the situation in the four regions. The conservation status of a habitat at the (national or European) biogeographical scale is defined in the Habitats Directive as the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions, as well as the long-term survival of its typical species within the considered territory. Favourable conservation status of a habitat refers to a situation where the habitat is prospering (in both quality and extent) and has good prospects of doing so in future as well (ETC/BD, 2006a; Evans and Arvela, 2011).

The assessment of conservation status is based on four parameters (EC, 2005, 2011a):

- **area**, the sum of the sizes of the patches actually occupied by the habitat;
- **range**, the region in which the habitat is likely to occur, provided local conditions are suitable;
- **specific structures and functions**, encompassing typical species and various indicators of habitat quality;
- **future prospects** for the survival of the habitat in the biogeographical region.

Each parameter is assessed as one of four classes: 'Favourable', 'Unfavourable — inadequate', 'Unfavourable — bad' or 'Unknown', and the four parameters are combined to give an overall evaluation of conservation status using the same four classes.

In the case of 'structure and functions', many Member States have taken the approach of scoring structures and functions at local (habitat patch or site) scale, followed by a data aggregation per category (sometimes weighted by patch area) to the biogeographical level. In this way, the assessed structures and functions can be tailored to each specific habitat. Ideally, the sample sites should follow a probability-based sampling design.

Box 6.2 Case study: assessment of habitat conservation status for Article 17 reporting in Greece

A methodology was recently adopted for implementation throughout Greece; one of its aims is to establish a monitoring network of permanent plots for surveillance and overall conservation status assessment of the Annex I habitat types at national scale (in compliance with Article 11 of the Habitats Directive). Another is to meet requirements to fulfil the Article 17 of the Habitats Directive reporting obligations (Dimopoulos et al., 2005 and 2012).

A bottom-up methodology was set up, i.e. from local level (site) to national level, both inside and outside the Natura 2000 network. At local scale, the conservation degree (CD) of each habitat type was assessed in the field using a protocol to quantify its structure and function, based on the following parameters: i) typical species (record of their presence, relative abundance and vitality); ii) specific structure and functions for the assessment of the CD; and iii) pressures and threats to predict the future prospects of structure and functions. The protocol is designed to reflect the ecological as well as geographical differentiation of the communities assigned to each habitat type, since different combinations of typical species are used for the geographical and ecological habitat subtypes.

All mentioned parameters are assessed locally, through fieldwork, for each habitat type. One methodological problem was finding a method to upscale from each field plot/area assessed to the 10 x 10 km cell at site level and then to national level. The simplest rule was to use the mode of assessments for each upscaling step. Therefore, from the protocol assessment at each plot/area, one proceeds to the grid cell assessment, using the minimum score for cells with ties, and finally to the assessment of the CD of the structure and functions for each habitat type at site level. The overall local assessment of prospects of structure and functions is calculated according to the score combinations of their actual status, future trend and future status.

Following the reporting guidelines, another important parameter for the conservation status assessment of habitat types is their area of occupancy (AOO). The AOO is measured using field data and modelled data sets for the regions outside Natura 2000. The extent (range) of occurrence (EOO) and the trends of both distribution parameters (AOO and EOO) will be estimated, as will their favourable reference values.

To summarise, for each habitat type at national scale, the score of four criteria is assessed: specific structure and function (upscaled values from plot/area to site and then to national scale), future prospects (upscaled values from plot/area to national scale), AOO (assessed at national scale) and range (assessed at national scale).

The parameter 'future prospects' is intended to indicate anticipated future status and future trends in a habitat's area, range and structure/functions, using the expected impact from threats in the next reporting period. Their assessment is mainly based on ancillary data and expert judgment, using various available data sources. For instance, trends on atmospheric nitrogen deposition derived from national environmental (e.g. air quality) monitoring schemes can be compared with known critical load thresholds for habitats of nutrient-poor environments.

To assess a habitat type, information is required on its total area and distribution, both of which can be derived from habitat maps, when available. Some mapping projects are designed to record information on habitat quality as well.

Photo 6.1 Monitoring habitat quality in the Český kras Natural Park, Czech Republic © J. Ichter

Monitoring and assessing habitat quality

Monitoring the local quality of individual habitat patches can serve various purposes: it provides direct input to site managers and serves as a baseline for the appropriate assessment of future plans and projects. Moreover, through aggregation, it can be used to complete standard data forms and contribute to assessing structure and functions for reporting under Article 17.

Habitat type is a pivotal factor in determining which variables need to be monitored. Several Member States have elaborated a framework to assess the local quality of habitat patches, using indicators and threshold values adapted to the specific habitats and the regional or national context (e.g. Verbücheln et al., 2002; Ellmauer, 2005; Søgaard et al., 2007; T'Jollyn et al., 2009). The case studies in Boxes 6.3 and 6.4 set out approaches adopted in different regions of Belgium.

Box 6.3 Case study: assessing habitat quality in Flanders

In Flanders (Belgium), the central objective was to produce a scientifically sound yet easily applicable tool that would allow the quality assessment of a habitat patch in a single field visit (at a suitable time of the year) by experienced, but not necessarily expert, botanists, with limited means and equipment (T'Jollyn et al., 2009 and further editions). Conceptually, the tool was based on a German approach (Verbücheln et al., 2002).

Typically, three categories of indicator are considered: habitat structure, vegetation and disturbance. For each of these groups, the chosen indicators and their threshold values can be adapted to the habitat. For instance, a typical indicator of a good habitat structure for many low-nutrient habitats is variation in plant life forms; for forests, it is the distribution of tree stem diameters. Vegetation indicators usually focus on the presence and cover of habitat key species (e.g. the grass *Corynephorus canescens* for dry sand heath). Disturbance indicators typically include tree and shrub encroachment in open habitats, and invasive alien species (e.g. the non-native moss *Campylopus introflexus* for dry sand heath) in all types of habitats.

Since this type of assessment essentially operates at the habitat patch level, to be useful at higher levels, it should be extended with a (model-based) approach to connectivity/fragmentation, taking into consideration metapopulation concepts of typical flora and fauna species.

For more information, see T'Jollyn et al. (2009).

Box 6.4 Case study: monitoring hay meadows at patch level in Wallonia, Belgium

Habitat patch-level monitoring includes area, spatial configuration (isolation) and quality. In many cases, it is restricted to Natura 2000 sites. Since appropriate management and assessment require exact locations of habitats within sites to be known, area and spatial configuration are usually derived from mapping. Habitat quality monitoring can be based on full census (which requires mapping) or point sampling (e.g. vegetation *relevés*).

A good example is the habitat monitoring scheme for the Annex I habitat type '6510 Lowland hay meadows' that has been set up in Wallonia (Belgium) since 2012. As it would be impossible to check every habitat patch at each reporting round, a standardised method using stratified sampling has been developed in order to have a good assessment of the conservation degree of a large sample of habitat patches across Wallonia. The method has taken into account constraints inherent in this kind of work: the number of people able to make the assessment every 6 years (in this case we can rely on 18 people available during a period of 6 weeks between 1 May and 20 June), and the time needed to check the patches (presence/absence of the habitat + botanical survey).

It was decided to check a randomly selected set of 5 x 5 km square grid cells derived by subdividing the ETRS 10 x10 km grid used for Article 17. In order to acquire an accurate assessment for each subregion of Wallonia (Limous region, Condroz, Fagne-Famenne, Ardenne and Lorraine), 5 subsets of randomly selected cells were chosen. In 2012, the assessment started with a theoretical set of 215 grid cells to be checked (at a mean estimated rate of 2 days/cell/expert), but experience showed that this was too ambitious, and only 125 cells have actually been surveyed in the 5 subregions.

Figure 6.1 Matrix used to assess patches of habitat '6510 Lowland hay meadows' in Wallonia, Belgium

6510 in Wallonia

Low- and medium-altitude hay meadows Assessment at the patch level			
Indicators	**A : very good**	**B : good to moderate**	**C : bad**
Area	≥ 1 ha	between 0,5 and 1 ha	< 0,5 ha
	A : very good	**B : good to moderate**	**C : bad**
Characteristic species (underlined) and species indicating a good status of conservation	*Anthriscus sylvestris* *Arrhenatherum elatius* *Avenula pubescens* *Centaurea gr. jacea* *Crepis biennis* *Daucus carota* *Lathyrus pratensis* *Lotus corniculatus* *Sanguisorba minor*	*Brachypodium pinnatum* *Briza media* *Bromus erectus* *Campanula rapunculus* *Galium mollugo* *Geranium pratense* *Heracleum sphondylium* *Knautia arvensis* *Leontodon hispidus* *Leucanthemum vulgare*	*Colchicum autumnale* *Pastinaca sativa* *Pimpinella major* *Rhinanthus angustifolius* *Rhinanthus minor* *Saxifraga granulata* *Tragopogon pratensis* *Trisetum flavescens*
Number of characteristic species	≥ 7	between 4 and 6	= 3 (if < 3 it is not 6510)
Covering of characteristic species	≥ 50%	between 25 and 50%	between 10 and 25%
Disturbances			
Indicator of grazing management	*Bellis perennis* *Cynosurus cristatus* *Lolium perenne*	*Poa annua* *Ranunculus repens* *Rumex crispus*	*Rumex obtusifolius* *Taraxacum sp.* *Trifolium repens*
Covering of species	< 40%	Between 40 and 60%	>60%
Indicator of eutrophication	*Alopecurus pratensis* *Bromus hordeaceus*	*Cirsium vulgare* *Phleum pratense*	*Poa trivialis* *Urtica dioica*
Covering of species	< 10%	Between 10 and 30%	>30%

6.1.2 *Habitat Red Lists*

Red List assessments of European habitats to date have mostly used a phytosociological typology and developed independently of habitat mapping.

Red Lists for terrestrial and aquatic plant associations, or assessment methodologies, have been produced for:

- the Czech Republic (Moravec et al., 1983 and 1995; Kučera, 2009);
- the Vorarlberg region of Austria (Grabherr and Polatschek, 1986);
- the French littoral zone (Géhu, 1991; Bioret, 2011);
- the Wadden Sea coast (Westhoff et al., 1993; von Nordheim et al., 1996);
- Spain (Loidi, 1994);
- the Baltic Sea (von Nordheim and Boedeker, 1998);
- Germany (Rennwald, 2000; Abdank, 2000 and 2004, Berg et al., 2004);
- Slovakia (Maglocky and Valachovič, 1996);
- the United Kingdom (Rodwell and Cooch, 1998);
- Hungary (Borhidi and Sánta, 1999);
- the Netherlands (Weeda et al., 2005).

At the level of alliances, a Red List also exists for the plant communities of the former USSR (Solomeshch et al., 1997) with unpublished reports for Latvia (Pakalne et al., 1995), the Czech Republic (Kučera et al., 1995) and Slovakia (Valachovič and Rodwell, 1995). In some of these countries, distribution maps of syntaxa are available at various scales and in different formats (dot distribution maps or vector graphics) which enable Red List assessments to be subsequently visualised. Very rarely, historic maps have used a typology enabling past trends in distribution to be assessed.

Red List assessments using national or regional classifications of habitats/biotopes have been produced for:

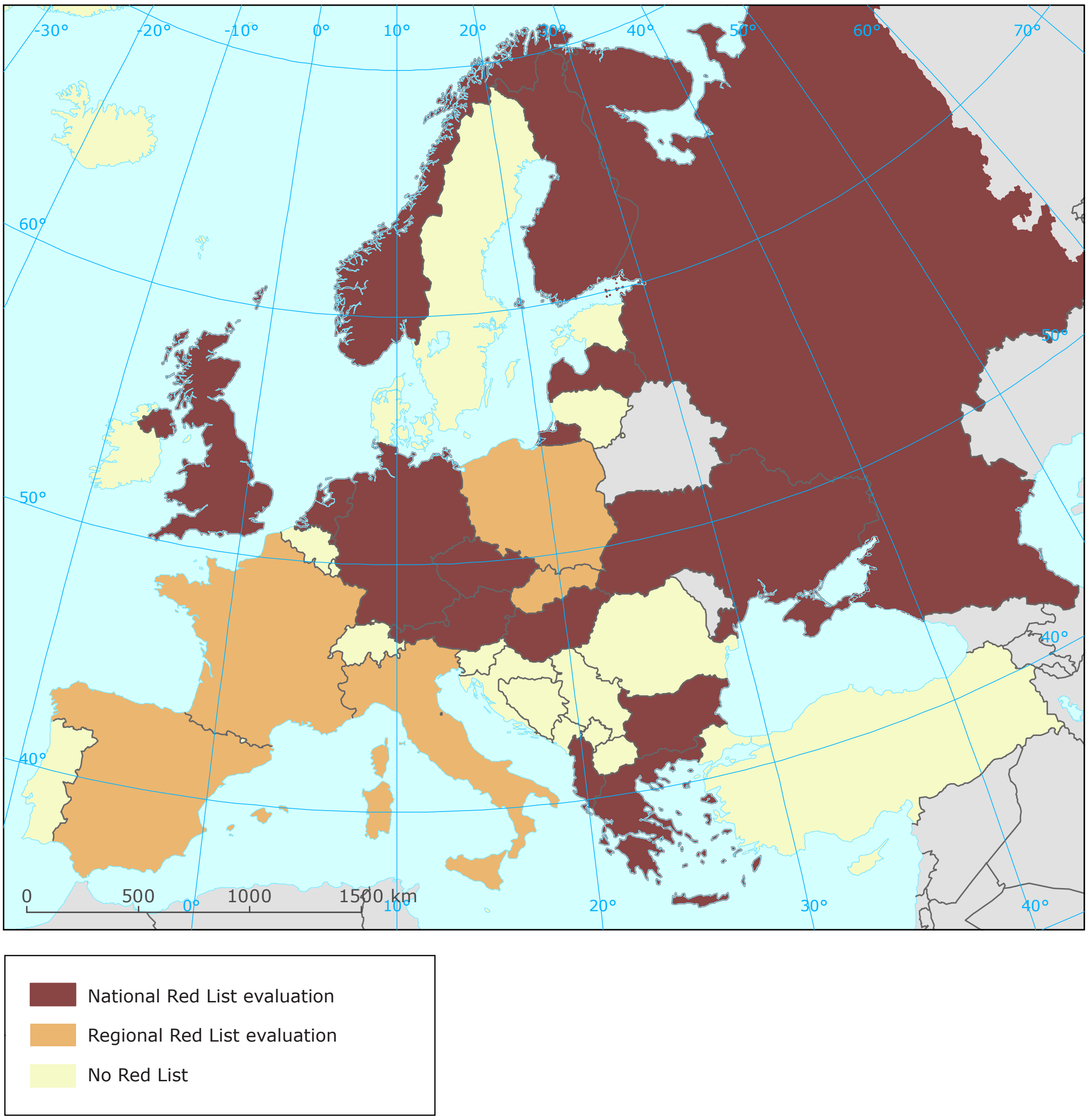
- Austria (Essl et al., 2002a, 2000b, 2004 and 2008; Traxler et al., 2005);
- Bulgaria (see http://e-ecodb.bas.bg/rdb/en/vol3);
- Germany (Riecken et al., 2006);
- Finland (Raunio et al., 2008);
- Norway (Lindgaard and Henriksen, 2011);
- humid habitats in France (Carre, 2012);
- the Wadden Sea (von Nordheim et al., 1996);
- the Baltic (HELCOM, 1998);
- the Mediterranean and the North-East Atlantic (OSPAR, 2003).

These studies have developed their own typologies, used the Corine or EUNIS classifications or Annex I of the Habitats Directive.

In future, more thorough applications of habitat mapping for Red List assessment could provide a better measure of the existing quantity of habitats in terms of AOO, extent of occurrence, and dispersal or degree of fragmentation of surviving stands. Comparison of maps from different dates could then demonstrate stability of distribution or trends of decline or increase. Using GIS technology, habitat mapping could enable Red List assessments to be integrated more thoroughly into habitat protection policy, landscape management, ecosystem services evaluations and spatial planning.

EU-funded work is ongoing for producing a European Red List of habitats. The method proposed in a scoping study carried out for DG Environment was compatible with recent IUCN proposals (Keith et al., 2013) and used the EUNIS habitat classification.

Map 6.1 Red List evaluations of plant communities or habitats in Europe



Note: Regional means that a Red List covers only part of a country, e.g. the littoral zone of France.

Source: Rodwell et al., 2013.

Box 6.5 Case study: the Austrian Red List of biotopes

The first Austrian biotope catalogue and Red List of biotopes were produced between 2000 and 2008 (Essl et al., 2002b, 2004 and 2008a; Traxler et al., 2005), largely following methods developed a little earlier in Germany (Riecken et al., 1994).

Ecosystem catalogue

Although Austria is a comparatively small country (84 000 km^2), its ecosystems are very diverse, encompassing mountainous regions of the eastern Alps but also lowlands in eastern Austria, and being located in the transition zone between temperate oceanic, temperate continental and sub-Mediterranean biogeographic zones. The Austrian biotope catalogue contains 488 ecosystems which are assigned hierarchically to 11 main ecosystem groups. A total of 383 biotopes are considered natural or semi-natural ecosystems of high nature-conservation value, while the rest (105) are highly modified ecosystems of no or little conservation value (e.g. intensively managed forests and grasslands, and many urban ecosystems).

The current extent of distribution of biotopes stored in the Austrian ecosystem distribution database (i.e. forest, mire, grassland and agricultural ecosystems) can be indicated by presence/absence maps using grid cells of circa 35 km^2. In most cases, the current distribution of ecosystems is well understood at this scale, and hence these distribution maps closely reflect the actual extent of occurrence in Austria.

Ecosystem Red List

The threat status of the biotope types gives cause for severe concerns. Around three quarters of the evaluated biotope types have been placed in a threat category. Five biotope types have been completely destroyed; 33 are threatened with complete destruction, 123 are vulnerable and 123 endangered. There are only 93 biotope types of high conservation value that are not threatened — predominantly biotope types at higher altitudes, some forest biotope types and geomorphological biotope types.

Mostly, restoration of biotope types is possible only under certain conditions, and requires a long time. A total of 110 biotope types cannot be regenerated or would take an extremely long period, and another 232 biotope types are hard to regenerate. A mere 41 biotope types can be regenerated under certain conditions and can thus be restored within shorter periods of time (around 15 years). These results show that there are clearly limits to the feasibility of habitat restoration.

The threats posed to biotopes in Austria are serious, and there is evidence that the conservation status of many types requiring traditional extensive land use is deteriorating. The most prominent threat is eutrophication, followed by abandonment of extensive, traditional forms of use and subsequent succession. Other important threat factors are biocide application and diffuse chemical inputs, land clearance, re-afforestation, intensification of land use and land development as well as interventions in wetlands such as river obstruction, drainage and energy use. In most cases, threatened biotope types are exposed to several threats simultaneously.

6.2 Strategic spatial planning

Habitat mapping has many applications in strategic spatial planning: for the implementation of green infrastructure or agri-environmental measures, environmental impact assessments, forest management and ecosystem service characterisation.

The Carta della Natura in Italy was developed in support of land planning.

Box 6.6 Case study: Carta della Natura in Italy

The Italian Carta della Natura system is based on the assumption that knowledge about the environment, including the distribution of habitats, is essential for effective implementation of environmental policy. It provides a complex, and at the same time synthetic, representation of Italy combining information on physical, biotic and anthropogenic factors, allowing the identification of natural value, risk of degradation and fragility of ecosystems.

Several different applications are possible: identifying ecological networks, environmental impact assessments and assessing strategies for environmental management. Carta della Natura can be used to identify habitats (including Annex I habitats) and homogeneous landscapes, allowing monitoring of conservation and restoration actions.

Future environmental scenarios and possible solutions to critical scenarios can be modelled by the input of appropriate data, in order to obtain different thematic maps. An example is the case of Sardinia, where an index of anthropogenic pressure, normally calculated considering numbers of inhabitants, was recalculated, taking into account the tourist inflows: the number of available beds (in hotels and other accommodation) can simulate arrivals in each municipality, and allows for a prediction of anthropogenic risk of impact on the natural habitat. Comparing the normal state to the stressed state helps identify the principal risk areas in some periods of the year (Laureti et al., 2011).

Another key application of Carta della Natura lies in helping projects that combat alien species invasion by identifying habitats easily invaded by alien invasive plants. Identifying sensitive areas allows restoration and monitoring to be efficiently targeted.

6.2.1 *From ecological networks to green infrastructure*

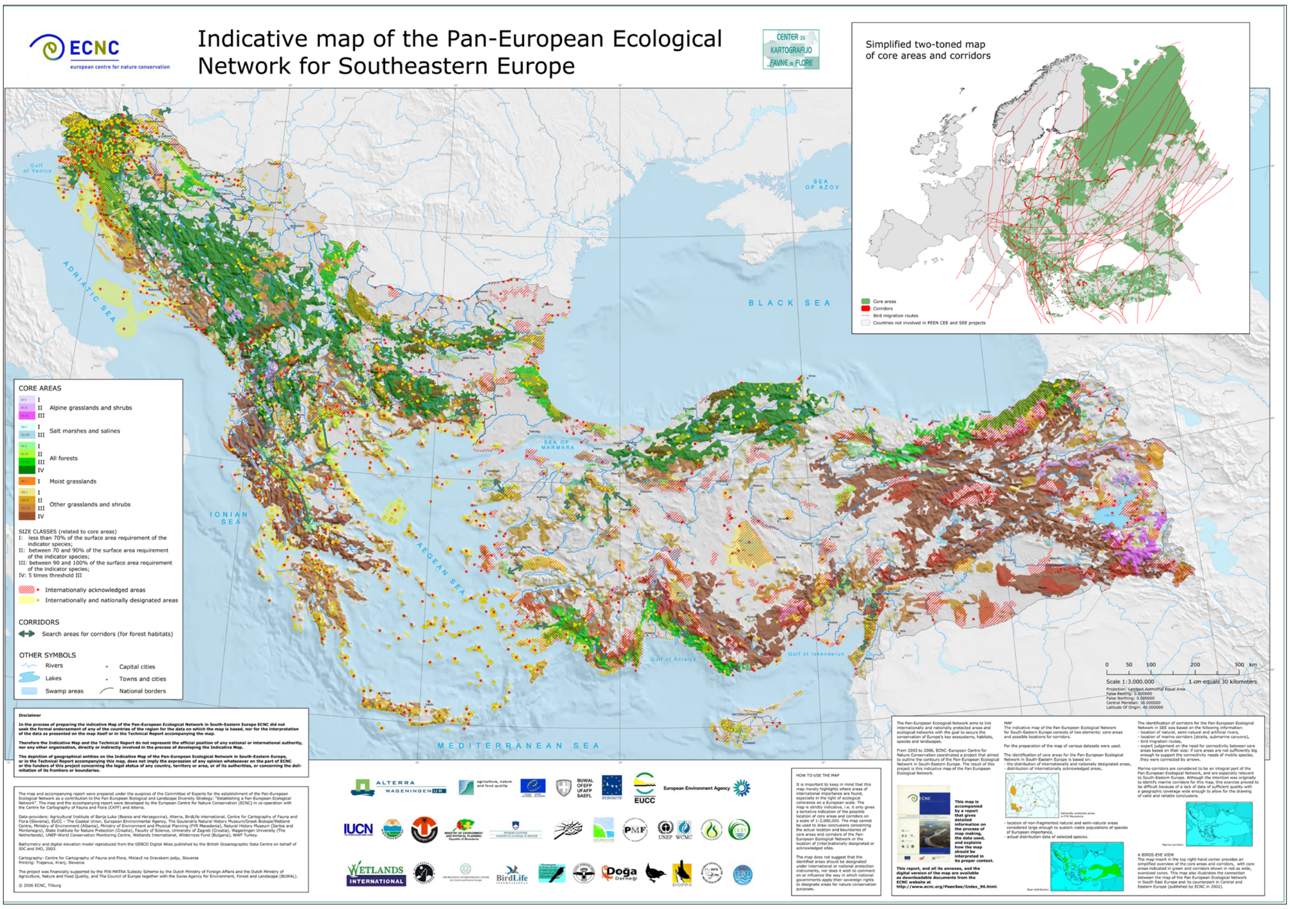
From the 1980s onwards, initiatives were developed in many countries in Europe to establish ecological networks at local, regional, national or supranational scales, mainly as a response to the increasing fragmentation of habitats and its negative effects on species mobility and migration. In recent years, interest in the concept of ecological networks has received an additional boost thanks to growing awareness of the potential threat posed by climate change to European biodiversity.

Regardless of the scale at which they apply (i.e. local, regional, national or international), almost all examples of ecological networks include some or all of the following components: core areas, generally protected areas; corridors including stepping stones; buffer zones; restoration areas.

In 1995, the Pan-European Ecological Network (PEEN) was launched as a key component of the Pan-European Biological and Landscape Diversity Strategy endorsed by 54 European countries at the Third Ministerial Conference 'Environment for Europe' in Sofia, Bulgaria. The PEEN was conceived both as physical network to be implemented on the ground to ensure the conservation of ecosystems, habitats, species, landscapes and other natural features of European importance, and as a coordinating mechanism through which the partners in the strategy could develop and implement cooperative actions, building on a variety of existing initiatives. These include Natura 2000, the European network of Biogenetic Reserves, the European Ecological Network (EECONET) concept, the Bern Convention (including the Emerald Network), the Bonn Convention on migratory species and the many national and regional ecological networks already under development.

Several indicative maps of the PEEN for Europe were produced: for central and eastern Europe (2002), for southern Europe (2006), and for western Europe (2006) (Bonnin et al., 2007).

Map 6.2 Indicative map of the PEEN for south-eastern Europe



Source: ECNC, 2006.

In most cases, mapping of elements of ecological corridors is based on land cover types (rather than habitats or vegetation types) combined with other ecological features such as protected areas, hot spots of biodiversity and species occurrence, as habitat mapping was not available.

The adoption by the European Commission of a Green Infrastructure Strategy in May 2013 is a key step in implementing the EU 2020 Biodiversity Strategy. In particular, Target 2 requires that 'by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems'. Maps of PNV have frequently been used to help plan restoration projects; the maps can help select vegetation appropriate for the site conditions (e.g. climate and soil conditions). For example, Rodwell and Paterson (1994) use the European map of PNV (Bohn et al., 2000–2003) (see Section 2.4) to suggest appropriate tree species for use in afforestation schemes in Great Britain, while Rodwell (2005) used the PNV map to visualise alternative future landscapes for an area in northern England.

One of the underlying concepts of green infrastructure is multifunctionality of areas, as, providing there is appropriate management, one area is capable of delivering multiple benefits: biodiversity conservation but also water retention, flood alleviation, cooling urban heat islands, climate change and more.

Box 6.7 Examples of components of a green infrastructure

Green infrastructure includes natural and semi-natural areas in rural and urban, terrestrial, freshwater, coastal and marine areas — from large wilderness areas to green roofs.

A working group set up by the European Commission in support of the preparation of the Green Infrastructure Strategy (see http://ec.europa.eu/environment/nature/ecosystems/index_en.htm) identified the following examples of components of green infrastructure.

- Areas with a high biodiversity value, e.g. protected areas such as Natura 2000 sites with their buffer zones.
- Areas of high actual or potential value outside protected areas such as floodplain areas, wetlands, coastal marshlands, extensive grasslands and forests.
- Sustainably managed agri-ecosystems and forests with high value also for ordinary biodiversity.
- Rivers and water courses, including floodplains, fens and riparian forests.
- Forest patches, hedgerows and wildflower field strips which can act as ecological corridors or stepping stones for wildlife, e.g. within intensively managed areas.
- Restored habitat patches and niches that have been created with specific functions and/or species in mind, e.g. to increase foraging areas and breeding or resting for species and to assist in their migration/dispersal, or to enhance the carbon storage and water cycles of those areas.
- Artificial features such as eco-ducts or eco-bridges that are designed to assist species movement across insurmountable barriers (such as motorways or paved areas) and to re-establish the permeability of the landscape, or some multifunctional, permeable soil covers in urban areas which allow the exchange of water and gases between the soil and the atmosphere (but only if they have a significant impact or are part of a broader action to increase biodiversity).
- Multifunctional zones that contribute to maintaining or restoring healthy ecosystems (e.g. maintaining peatlands wet or rewetting them, and organic agriculture and multifunctional forestry opposed to exclusively yield-oriented agricultural or forestry use).
- Urban elements such as urban and peri-urban forest and agriculture, biodiversity-rich parks, green walls and green roofs, hosting biodiversity and allowing for ecosystems to function and deliver their services. These elements should also connect urban, peri-urban and rural areas.
- Rural manmade structures such as stone closures and terraces, historical buildings and green hedges.

6.2.2 Environmental impact assessment

Environmental impact assessment (EIA) is a procedure that ensures the environmental implications of decisions are taken into account before the decisions are made. In the EU, two directives (the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and the codified Directive on the assessment of the effects of certain public and private projects on the environment (2011/92/EU)) aim to ensure that plans, programmes and projects likely to have significant effects on the environment are made subject to an environmental assessment, prior to their approval or authorisation.

Besides geological, hydrological, toxicological, acoustic, etc. criteria, biodiversity information is collected and evaluated. Assessment of biological data is particularly important in the case of projects influencing Natura 2000 sites, according the Article 6, paragraph 3 of the Habitats Directive. Data on habitats or vegetation from maps represent one of potential sources of information for the biological assessment.

Use of data from habitat mapping

Habitats are not only of conservation interest as habitat types; they provide the environment for species of both plants and animals. Habitat maps may already contain information about plant species, or at least one can assume the potential occurrence of species, and the entity responsible for the EIA can propose or order a survey targeted at potential sites. The information on quality and quantity of particular habitats can serve as proxy data for population size of particular species. For example, data on the quality and area of dry grasslands on calcareous substrates with orchids allow a rough estimation of the orchid population; information on the area, structure and amount of decayed wood of a beech forest can help with the estimation of conditions for fungi and insects bound to old forests.

Phases of environmental impact assessment

The EIA consists of several steps or phases, with screening and scoping being the first. Screening is the process of deciding whether an EIA is required. This may be determined by the type or size of the project (e.g. if it is greater than a predetermined surface area of affected land). Alternatively, it may be based on site-specific information. Site-specific information includes the presence of species or habitats of European interest. In this case, the use of information from habitat mapping is evident. The output from the screening process often takes the form of a document called an Initial Environmental Examination or Evaluation (IEE). The main conclusion will be a classification of the project, according to its likely environmental sensitivity. This will determine whether an EIA is needed, and if so, to what level of detail.

Box 6.8 Case studies from the Czech Republic

The habitat map of the Czech Republic covers the whole national territory, i.e. each occurrence of natural habitat is mapped, and the data are available from the Nature Conservation Agency upon request with no charge. In the Czech Republic, only persons authorised by the Ministry of Environment may carry out EIAs, and assessment of projects affecting Natura 2000 sites is subject to similar authorisation issued by the Ministry of Environment, in this case limited to Natura 2000 species and habitats only. Two examples of the use of the Czech habitat map are given below.

Focus on habitat and species inventory and conservation during a railway reconstruction
Reconstruction of a railway running along a river stream at the bottom of a canyon was proposed. The reconstruction also included slope stabilisation using mesh and fences. During screening, the office in charge could not exclude possible negative impacts of these security measures on Annex I habitats (rupicolous Pannonic grasslands, calcareous rocky slopes with chasmophytic vegetation and subcontinental peri-Pannonic scrub) in a nearby Natura 2000 site. The office in charge ordered a detailed inventory and assessment of these habitats during the scoping studies.

Compensation measures for dry grasslands and thermophilous forests after the increase of lime production
A lime factory planned an increase in production. During the production of lime, oxides of nitrogen are produced due to combustion at high temperature, and these represent a source of fertilisation after being washed from the air during rain into the soil. This constitutes a threat to low-productivity dry grasslands and thermophilous forests. During the EIA, a model of nitrogen emissions deposition was created; according to this model, several Natura 2000 sites would be negatively influenced. The owner of the lime factory signed an agreement to compensate for the negative effects with active management: grazing of dry grasslands and coppicing of thermophilous forests.

Scoping occurs early in the project cycle, at the same time as outline planning and pre-feasibility studies. Scoping is the process of identifying the key environmental issues, and is perhaps the most important step in an EIA. Several groups, particularly decision-makers, the local population and the scientific community, have an interest in helping to determine which issues should be considered.

When assessing impact of a project on a particular habitat type at a particular site, the person or office has to take into account the quality and quantity (area) of the habitat influenced, as well as its local/regional/national or European importance. The connectivity with the surrounding site of this habitat is also evaluated. It is useful to focus on several questions: how large is the habitat segment influenced by the project? How it will be fragmented, especially by linear projects? How it is connected with surrounding segments of the habitat? Large GIS habitat databases facilitate answers to these concerns. Similarly, detailed habitat mapping covering the area of a Member State or large region can serve as a basis from which to deliver sound data for decision-making, and is better than fragmented knowledge on particular protected natural areas only.

The office in charge can approve the project (issuing a positive statement) even when it has negative impact on the environment, e.g. habitats or species. In this case, usually health, defence or social benefits must prevail and compensation measures must be provided. With consistent habitat-mapping information, the office in charge can order the investor to improve conditions in neighbouring sites of a particular habitat.

6.2.3 *Agri-environmental measures*

Agri-environmental measures were introduced into the EU's Common Agricultural Policy (CAP), and are obligatory in all EU Member States.

In order to achieve national targets for uptake of agri-environmental measures, it is necessary to develop baseline data for understanding the critical factors in the environment and the wider countryside. For instance, to maintain high water-quality standards in a region, it is important to gather baseline information about the quality of surface water and groundwater. For maintaining and protecting natural ecosystems, gathering of baseline data will provide information about the specific vulnerability of these ecosystems for management options at farm level. In nature generally, baseline data should fulfil the following criteria:

- data should be available on a plot- and landscape-mapping scale;
- data from recent years should be used;
- data should reflect ecosystem diversity at plot and landscape level;
- data should be reproducible in future through monitoring;
- collection of data should be random;
- the mapping methodology should be based on standards accepted at European level by experts;
- mapped data can be interpreted for the creation of landscape-ecological models;
- mapped data can be adequately interpreted for the development of agri-environmental measures.

This clearly indicates an important role for mapping.

Description of a grassland mapping system for agri-environmental policies

In the framework of national grassland inventory projects in central and eastern Europe, a monitoring system for mapping baseline data has been developed by grassland vegetation experts from the region, and is supported by the Royal Dutch Society for Nature Conservation (Veen and Šeffer, 1999; Veen et al., 2009).

The monitoring system includes the following phases:

- localisation at national level of grassland complexes via the interpretation of satellite images;
- checking the actual situation of localised grasslands based on expert knowledge in the region;
- preparation of a preliminary grassland classification system, based on phytosociology with diagnostic species;

- mapping of grassland vegetation by taking stratified samples over the country with data held in a vegetation database;
- statistical classification of botanical data by using diagnostic plant species at alliance level;
- preparation of a strategy for the management and conservation of high nature-value grasslands.

This system of mapping and interpretation is compatible with the theoretical criteria noted above, because the results are available at several scales and reflect the main diversity in ecosystems.

Vegetation data are also closely connected with abiotic parameters such as climatic conditions (Veen and Metzger, in Veen et al., 2009). Management intensity can be shown, as it is linked to the abundance of nitrate-tolerant species. Research has identified which plant communities reflect different management regimes or land abandonment. Standard classifications of European grassland vegetation are available for all regions of the EU (e.g. Ellenberg, 1982; Matuszkiewicz, 2001; Oberdorfer, 1998; Horvat, 1974; and Doniţã, 1992). By harmonising this methodology across the EU, it would be possible to build up a European database for grasslands (see Section 3.1.2).

Photo 6.2 Pannonian dry grassland (*Seslerio-Festucion pallentis*) near Vienna, Austria © J. Ichter

Box 6.9 Case study: national grassland inventory in Slovakia

The grassland inventory of Slovakia was organised by the non-governmental organisation (NGO) DAPHNE — Institute of Applied Ecology, and it ran from 1998 to 2006. Later phases of the inventory were also funded by the Global Environmental Facility and the Slovak Ministry of the Environment.

Field mapping was carried out at a scale of 1:25 000, based on military maps covering the whole country. Selected classes from Corine Land Cover (844 000 hectares) were used to preselect potential grassland occurrence and were shown on the working maps used by surveyors.

A coordinating team developed the mapping methodology (Šeffer et al., 1999), which was revised after the first year (Šeffer et al., 2000). Mapping focused only on grasslands with a natural species composition. Polygons of more or less homogenous grassland vegetation were mapped in the field, and surveyors recorded the vascular plant composition of each polygon; they estimated the cover using a simple Tansley scale (3 for cover of more than 50 %, 2 for cover between 1 % and 50 % and 1 for cover of less than 1 %), and a set of other important data (e.g. habitat type, cover of trees and shrubs, and management).

More than 100 surveyors were involved, and they recorded 16 738 polygons with an area of 323 000 ha, representing more than 96 % of the preselected grassland area in Slovakia. The project database contains nearly 1 million records of species occurrence within mapped polygons.

Data from the inventory were used for several purposes. They served as a basis for the identification of sites for the Natura 2000 network, where DAPHNE was responsible for the preparation of the scientific proposal of SCIs, and proposed the best grassland sites for the network. However not all of these were accepted by the Slovak authorities for the final proposal.

The information system was widely used for the implementation of the agri-environmental programme. The scheme for the conservation of semi-natural and natural grasslands has been an integral part of the programme since the year 2003. The farmers could apply the scheme only on grasslands with natural species composition certified by a special authority (DAPHNE from 2003 to 2006 and from the State Nature Conservancy of the Slovak Republic since 2007). The certification was mainly based on data from the national grassland inventory. Thus the inventory helped to target agri-environmental payments.

Last, but not least, the data from the inventory may be used as a baseline for monitoring activities. It is expected that they will be used for the official monitoring of Natura 2000 habitats, recently initiated. In 2012, they were used in the monitoring study focusing on the implementation of the agri-environmental programme. Since most of the data were obtained before Slovakia joined the EU, comparison with the current state of the grasslands will allow an evaluation of the impact of EU subsidies on grassland biodiversity.

6.2.4 Forest management

Box 6.10 Biotope mapping in French forests

Principle
Biotope mapping in forests has been ongoing in Germany since the 1980s, as part of forest management. This eco-diagnostic method for sustainable integrated management of forests was adapted for use in France during the 1990s by the Office National des Forêts (Lalanne, 2001). The goal of biotope mapping in forests is to give an overview of the biodiversity of a forest, covering all plant associations present within a given forest unit, as well as their conservation status and their structure. It also focuses on the associated non-forest habitats and the substitution habitats important for nature conservation. Finally, it allows identification of different vegetation successions leading to the closest natural forest or to semi-natural ecosystems of high conservation value (e.g. *Calluno-Ulicetea* heaths, *Festuco-Brometea* grasslands).

Methods
In the field, each management unit is split into floristically homogeneous vegetation plots represented at a scale of 1:5 000. For each unit, a phytosociological relevé is made. With the aid of predefined grids, the structural diversity of these units and their richness in subordinated plant communities, as well as their richness in structuring elements or micro biotopes (e.g. standing dead wood, hollow trees, uprooted trees) are quantified.

Subsequently, the different data sets are computerised, prior to analyses.

Applications
Various applications are possible with the biotope approach to forest mapping.

It allows:

- naturalness assessments of forest plots, i.e. the difference between the PNV (the meta-climax) and the actual vegetation;
- diversity and rarity assessments in terms of plant associations (horizontal diversity, vertical diversity and structural complexity), landscape mosaics or eco-complexes, but also for animal and plant species;
- identification of rare and threatened habitats, both at European level (Habitats Directive), and national, regional or even local level;
- the creation of protected woodland areas of ecological interest, integral or managed reserves and old-growth units (or forest maturation units).

6.2.5 *Monitoring landscape changes*

Box 6.11 Vegetation mapping for landscape change detection in Norway

Vegetation mapping in Norway

Most of the vegetation maps in Norway are at scales from 1:2 000 to 1:5 000 (Bryn, 2006). The typology used includes 45 vegetation types and 9 other land cover types. Also, a number of additional data are recorded for each polygon, providing important information which by definition is not included in the vegetation type; examples include coverage of lichen, willow thickets, grass-dominated forms and management status. The methodological approach combines fieldwork with interpretation of aerial photos. More than 10 % of Norway has been mapped (Rekdal and Bryn, 2010).

Forests expansion in Norway

By comparing actual vegetation maps with interpreted previous vegetation maps and old aerial photos, landscape changes can be detected at a specified spatial scale. Following this method, it has been documented that during recent decades, forests have expanded into new areas throughout Norway (Bryn and Hemsing, 2012). Explanations for forest expansion have focused mainly on climate or land use changes. Modelling of PNV from actual vegetation maps has shown that many ecosystems in Norway are still strongly influenced by previous land use, and because of land use abandonment, further changes should also be expected in the future (Hemsing and Bryn, 2012). As much as 15.9 % of mainland Norway is presently deforested by previous land use (Bryn et al., 2013).

Separating the effects of land use change from those of climate change

Through interpretation of previous vegetation as well as modelling of both PNV and climate change scenarios, and using the same actual vegetation map as a basis, in combination with other methods (e.g. forest growth measures), it is possible to spatially separate the effects of natural forest regeneration following changed land use from the forest expansion related to climate changes (Bryn, 2008; Bryn et al., 2013). On a vegetation map study from a mountain region in southeast Norway, it was shown that raised forest limits and forest range expansion often attributed to recent climate change was instead a product of natural forest regeneration, a process that was climatically retarded from 1959 to 1995 (Bryn, 2008). For the period from 1995 to 2006, the data indicated a preliminary effect of climate change escalating natural forest regeneration and probably pushing future forest limits to higher altitudes.

Photo 6.3 Vegetation mapping in Norway © Anders Bryn

6.3 Mapping ecosystems and their services

Society receives many benefits from well-functioning ecosystems providing several services (e.g. agricultural products, timber, erosion control, pollination and aesthetic beauty) that support human societies and the well-being of their citizens. Some of these services are relatively well absorbed by the markets, whereas others may be considered as commons endangered by spontaneous socio-economic processes (Kumar, 2010). In order to optimise human land use and policy decisions, the entire spectrum of ecosystem services needs to be taken into consideration. But this only works if ecosystem services are being quantified and actively monitored. We cannot manage what we cannot measure.

Action 5 of the EU Biodiversity Strategy calls upon Member States to 'map and assess the state of ecosystems and their services in their national territory by 2014'. Inevitably, the first step of this ambitious and challenging commitment is to generate maps of the ecosystems, to be used as a basis for evaluation of the services they provide. Ideally, all ecosystem types that act as functional units in delivering services should be mapped and evaluated separately. However, data availability, lack of time and a need for coherence and standardisation all point towards using readily available land cover maps as a substitute for ecosystem maps of a higher thematic resolution. The majority of the existing case studies propose an ecosystem typology largely based on the Corine Land Cover categories (Burkhart et al., 2009, Maes et al., 2011 and 2012).

Harmonisation of the assessment activities of the Member States is an important ongoing activity of major European actors (including DG Environment, the EEA, the Joint Research Centre (JRC) and the Mapping and Assessment of Ecosystem Services (MAES) working group of the EU). However, this harmonisation must have some degree of flexibility, in order to reflect the specific ecological, social and historical context of each Member State. Accordingly, Member States are encouraged to use a more detailed ecosystem typology if available, with the only restriction being that the more detailed classes (e.g. habitat types or vegetation) should be linked to the EU-level typology. Thus, national habitat or vegetation maps can provide an ideal contribution to the ecosystem service assessments of the Member States. A recent publication from the European Commission links the MAES typology to the EUNIS habitat classification (Maes et al., 2013).

In addition to discriminating ecologically relevant habitat types within the same land cover categories, habitat maps may contribute further relevant information for ecosystem service assessments. For example, several previous mapping programmes have incorporated qualitative descriptors for the quality of the mapped habitats under various names (e.g. ecosystem state, ecosystem health, ecological integrity, naturalness, hemeroby, vegetation condition and degradation level) (Czúcz et al., 2012). As degradation compromises the capacity of ecosystems to perform certain services, data on the ecological status of ecosystems can be of pivotal policy relevance in several contexts (e.g. ecosystem service assessments, reporting and monitoring activities, or strategic planning). Even Action 5 of the Biodiversity Strategy refers to the need to 'map […] the state of ecosystems' and not simply to 'map the ecosystems'. Of course, for habitat quality mapping to constitute a useful input for European-level policy processes, the definitions and classification schemes used to evaluate the degradation levels should be harmonised, as should the habitat categories.

Table 6.1 Ecosystem typology recommended for use in European ecosystem service assessments by MAES working group

Major ecosystem category (Level 1)	Ecosystem type for mapping and assessment (Level 2)
Terrestrial	Urban
	Cropland
	Grassland
	Woodland and forest
	Heathland and shrub
	Sparsely vegetated land
	Wetlands
Freshwater	Rivers and lakes
Marine	Marine inlets and transitional waters
	Coastal
	Shelf
	Open ocean

Source: Maes et al., 2013.

6.4 Key references

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7 A historical review of vegetation and habitat mapping in individual European countries

How individual countries implement vegetation and habitat mapping is to a large extent the result of academic and cultural specificities, but it also often reflects the political history of the countries. It is thus useful to get a perspective of the historical development of vegetation and habitat mapping within different European countries.

The following is not a comprehensive review of all European countries, but rather an overview of the types of mapping undertaken and of the variations in approach across Europe. Phytosociological methods tend to dominate in central and particularly southern Europe, whilst other approaches are used in northern Europe, especially in Scandinavia. The countries are presented in alphabetic order, with Denmark, Finland, Iceland, Norway and Sweden, grouped together as Nordic.

7.1 Bulgaria

7.1.1 History

The earliest vegetation maps of Bulgaria were produced at the beginning of 20th century. In 1939, the first detailed forest map was produced at a scale of 1:20 000 with 12 mapping units. In 1961, this map was improved and updated, resulting in 21 mapping units. In the same year, a large project to map the vegetation of the whole country was undertaken by a team that included researchers from the Institute of Botany at the Bulgarian Academy of Sciences. Information was collected following the dominance approach.

As a result of this survey, the map legend was published in 1969 (Velchev et al., 1969). The scale was 1:200 000, and 1:50 000 topographic maps were used for field surveying. The legend was structured to provide information about both potential and contemporary vegetation. The units were divided in 4 groups according to altitudinal belts: high mountain vegetation (8 units), coniferous forest belt (15 units), beech forest belt (15 units) and oak forest belt (39 units). Unfortunately, after several years of intensive field survey, the project was abandoned and no sheets were published.

In 1973, the 'Atlas of the people's Republic of Bulgaria' was published. It included a vegetation map (1:1 000 000; Bondev, 1973) and a forest map (1:1 500 000; Bondev and Jordanov, 1973).

The most recent vegetation map was developed and published in 1991 (Bondev, 1991). It contains 150 mapping units hierarchically organised from associations to formations. The primary (potential) vegetation is represented by 97 units (89 forests, 2 scrub and 6 herbaceous) together with secondary vegetation types in 53 units (10 forests, 13 scrub, 11 herbaceous and 19 agricultural lands). During the 1970s and later, several maps were produced that served regional purposes, for example, vegetation in nature reserves, natural parks or other protected areas (e.g. Meshinev et al., 1994 and 2000).

7.1.2 Recent developments

After political changes in 1990, phytosociologists in Bulgaria started using the Braun-Blanquet approach, aiming to get closer to European standards. In 2001, the National Grasslands Inventory Project funded by the Dutch Programme International Nature Management started. The final product of this inventory was a map at a scale of 1:25 000. Over a period of 3 years (2002–2004), the grassland survey was carried out by experts and 350 000 ha below 1 700 m altitude were mapped as important semi-natural grasslands. For the purposes of the inventory, 260 topographic maps at 1:25 000 scale were used, together with 200 satellite photographs at the same scale. The classification of mapped grasslands included 28 mapping units, mostly at the level of alliances (Meshinev et al., 2005).

Implementation of the EU Habitats Directive, particularly the site selection for the Natura 2000 network, led to new mapping activities. From 2011 to 2013, the 'Mapping and Identification of the Conservation Status of Natural Habitats and Species — Phase I' project ran, covering all Natura 2000 sites (34.3 % of the country). This project will assist the Ministry of Environment and Waters to continue the process of building and managing the Natura 2000 network. The work was based on maps, modelling and field verification. There is still a need for large-scale maps of actual vegetation in the country, at the level of alliance at least, to provide information on biodiversity and management of natural resources.

7.2 Estonia

7.2.1 *History*

The first vegetation mapping in Estonia, at the end of the 18th century, was undertaken for forestry purposes. Some 150 forest surveys are known from the 1820s, including mapping of forest stands and management plans (Meikar and Viilma, 2002). In 1922, J. G. Granö divided Estonia into 15 districts based on plant physiognomy; in 1925, K. R. Kupffer published the first map of plant geographical regions of the Baltic States, revised for Estonia in 1935 by T. Lippmaa. In 1934, Lippmaa initiated a programme for Estonian vegetation mapping at a scale of 1:42 000 with descriptions of 42 mapping units. Due to the Second World War, this mapping was not concluded until 1955, with a generalised map at a 1:200 000 scale prepared in 1956, and an exhaustive analysis of the mapping data was published by L. Laasimer in 1965. Her vegetation classification system is ecological: the associations are established based on the habitat's soil properties and moisture conditions in addition to the species composition and their abundance. The associations are merged into groups on the basis of soil characteristics, whereas the association groups are united into series by the dominating life forms and habitat's water regime, and the series into higher units on the basis of water regime. In 1946, an inventory of mires began, although the first general map of distribution of main types of mires had been published in 1922 (Wellner, 1922). On the basis of mire inventories, a 1:600 000 map was published in 1961 (Торфяной фонд Эстонской ССР [Peat inventory of the Estonian Soviet Socialist Republic], 1961).

7.2.2 *Recent developments*

After regaining independence in 1992, mapping of Estonia's vegetation and habitats was required in order to implement the EU Habitats Directive and to join up with the European mapping projects. Thematic country scale surveys are usually based on Landsat satellite information and GIS (e.g. Remm, 2004; Aaviksoo and Muru, 2008). The areas included in the Natura 2000 network were mapped for the first time in 2004. Mapping was also one of tasks of several habitat inventory projects, e.g. for coastal and floodplain meadows (Leibak and Lutsar, 1996), establishment of the Estonian Forest Conservation Area Network (Viilma et al., 2001) or the assessment of the state and conservation value of mires (Paal and Leibak, 2011).

7.3 France

7.3.1 *History*

After the Second World War, the Centre national de la recherche scientifique (CNRS) established a unit in Toulouse in 1947 to produce a 1:200 000 scale map of land cover vegetation in France, under the leadership of Henri Gaussen. This ambitious project aimed to give a geographic and statistical inventory of 'ground cover' and provide information on the 'dynamism' of the country›s vegetation and potential land value.

Between 1947 and 1991, 64 map sheets were published by 52 different authors.

Each sheet features:

i) the map sheet at 1:200 000 scale, showing vegetation cover at the time the map was produced;

ii) a series of 8 smaller 1:1 250 000 insert maps giving further details on climate, soil, potential vegetation, and other valuable information.

The 1:200 000 land cover vegetation map is based on the general principle that vegetation is distributed into coherent sets of 'vegetation series' or 'vegetation stages' in mountain areas, with geographical distribution patterns determined by local habitat, climate and edaphic conditions. Each stage or series can be defined by a dominant forest species.

However, in countries like France, with a long history of strong anthropogenic pressures, trees species do not always fall into dense dominant forest populations; instead, each vegetation series or vegetation stage features various types of vegetation, such as grassland, heath, and broadleaf woodland.

The map also makes intense use of colour, where the colour itself charts the vegetation series. The colours essentially reflect the meanings intuitively attributed to the primary colours: red evokes heat and so is assigned to series whose dominant species require the hottest climate, whereas blue tends to translate humidity and so is assigned to species like beech that prefer a certain level of moisture. These colour extremes are sub-shaded into various colours reflecting the transition from hot and dry to cold and wet.

Tone reflects vegetation status: darker tones reflect communities currently approaching climax vegetation, i.e. vegetation under little if any anthropogenic pressure and reaching an ecosystem balance under the climate-defined habitat, whereas lighter tones represent progressively more advanced states of vegetation disturbance. Cropland, which is a stage with virtually no natural vegetation, is logically shown as white.

These 1:200 000-scale land-cover vegetation maps of France thus offer a snapshot of local vegetation, biodiversity and ecological conditions, while functioning as a valuable national spatial planning tool. They also serve as an equally valuable tool for gaining insight into plant ecology and plant species responses to environmental change.

7.3.2 *Recent developments*

See Section 1.2.

7.4 Germany

7.4.1 *History*

Germany has a long history of vegetation mapping based on the classical phytosociological approach with plant syntaxa, developed mainly by R. Tüxen and his collaborators in the 1940s. Tüxen founded a German office (Reichsanstalt) for vegetation mapping in 1934, which in 1955 became a national research institution for vegetation science and convened international conferences on vegetation mapping (Braun-Blanquet, 1959). The results are maps of the actual vegetation and interpreted maps of PNV.

In Germany, vegetation mapping largely focused on PNV maps, originally planned on a scale of 1:25 000 and 1:50 000 (10 exemplary maps were published). Later, 9 maps were published at a scale of 1:200 000, with 5 maps covering all of eastern Germany (the former German Democratic Republic). Both attempts remained incomplete because of a lack of funding and sufficient trained geobotanists working for the projects.

In the context of creating the PNV map of Europe (Bohn et al., 2000/2003) (see Section 2.4), an overview map for Germany was compiled at the scale of 1:1 000 000 in 1997. Since then, a complete set of 6 maps at the scale of 1:500 000 has been compiled, covering all of Germany (Suck et al., 2010). An accompanying text volume is in preparation and will be published in 2013 (Schröder, in prep.). The maps are also available as GIS data, and will be published as an INSPIRE-compliant web mapping service. Regionally, many detailed vegetation maps have been produced in scientific field studies and for physical planning, both for impact assessments and for nature conservation planning. There are also some examples of sigma-association maps (e.g. Schwabe, 1987).

7.4.2 *Recent developments*

In the 1970s, biotope mapping projects were launched in most of the *Bundesländer* (German federal states) with growing awareness of whole ecosystems and biotopes being under threat and suffering from increasing pressures. Biotopes are defined as an area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals (Ssymank et al., 1993). They represent an integral ecological unit, for both plant and animal communities, and are used as mappable units in nature conservation planning and management.

Biotope mapping definitions and programmes were developed independently in the 16 *Bundesländer*, and in most cases a selective mapping of those biotopes considered to be threatened was carried out. In some cases, this was restricted to protected areas only. Most of the *Bundesländer* have refined and adapted their methods, and now have data from three full successive mapping periods. The actual situation and availability of data are summarised in Kaiser et al. (2013). In 1993, a first, German, standard list of biotopes (Blab und Riecken, 1993) was published; in 1994, a first edition of the *Red Data Book of German Biotope Types* appeared (Riecken et al., 1994). The second edition (Riecken et al., 2006) is currently available, and a third edition is scheduled for 2016.

The 1992 EU Habitats Directive introduced a list of habitats to be protected throughout the EU in Natura 2000 sites. In Germany, a *National Interpretation Manual* (Ssymank et al., 1998, preliminary version 1993) and later regional adaptations by the German federal states were used for mapping Annex I habitats to document the status quo of SCIs, and also for appropriate assessments under Article 6 where necessary.

Bundesländer Biotope mapping schemes are still independent, but definitions are more homogenous than in the past, due to adaptations both to the *Red Data Book of German Biotope Types* and to the Habitats Directive. Biotope mapping and vegetation mapping data both constitute important information for nature conservation policies, planning and management of protected areas. EU reporting requirements for the Habitats Directive (Article 17) have reinforced the need for regular updating/remapping of biotopes in Germany, and for partly counterbalanced financial cutbacks in nature conservation.

7.5 Italy

7.5.1 History

The application of phytosociology to the analysis and spatial distribution of vegetation in Italy in the 1940s led to the publication of a local-scale physiognomic vegetation map (Sappa and Chiarrer, 1949). The first phytosociological map was published by V. Giacomini in 1954, followed in 1955 by Giacomini and S. Pignatti's vegetation map of the Spluga region.

Italy was mapped at a small scale (< 1:1 000 000) by several authors; the earliest example is the botanical map of Italy (1:5 000 000) by A. Fiori (1908). This was followed by other maps: plant formations (1:2 500 000) (Fiori, 1936); a map of the vegetation areas in Italy (1:5 000 000) (Beguinot, 1933); a vegetation map of Italy (1:6 000 000) (Giacomini and Fenaroli, 1958); forest vegetation of Italy (1:2 000 000) (Tomaselli, 1973); and actual vegetation (1:1 000 000) (Fenaroli, 1979).

7.5.2 Recent developments

More recently, in 1992, Pedrotti published a map of the actual vegetation of Italy (1:1 000 000) which is focused on physiognomic-vegetational types, providing accurate, though not very detailed, information on 54 vegetation types.

In 2010, Blasi coordinated a large team of regional experts from several universities: they adopted a new integrated method to produce a national map of vegetation series at a scale of 1:250 000. This map, which is accompanied by a volume presenting the vegetation of each administrative region, consists of 3 sheets printed at a scale of 1:500 000, but is based on mapping at scales ranging from 1:50 000 to 1:100 000 (Blasi, 2010).

The Map of the Vegetation Series of Italy combines, for the very first time at a national scale, the inductive approach of the European School of Phytosociology with the deductive approach of the Ecoregion classification developed in the United States in the mid 20th century. Application of the Ecoregion classification for more than 10 years (Blasi et al., 2000; Capotorti et al., 2012) has led to the definition of land environments (environmental units) that are characterised, depending on the scale adopted, by the same type of vegetation series. In brief, the Map of the Vegetation Series of Italy highlights the potential diversity of vegetation in Italy, while the regional-scale monographs analyse current vegetation by describing the syndynamics taking place, i.e. each stage of every vegetation series.

Another innovative element was the exclusive use, even for the vegetation series, of classical phytosociological *relevés* as opposed to *synrelevés*, which makes it objectively even more difficult to recognise and map homogenous reference environments inductively. In addition to the innovative methodology, using both deductive (the cartographic definition of ecologically homogeneous environments) and inductive (classical surveying of the vegetation) processes, this nationwide mapping project has yielded an extraordinary amount of data that have been used to identify and map vegetation series of both extremely limited and very extensive areas. For example, the *Junipero hemisphaericae-Abieto nebrodensis sigmetum* series covers 320 hectares and accounts for 0.001 % of the area of Italy, while the *Oleo sylvestris-Querco virgilianae sigmetum* series covers 1 517 000 hectares and accounts for approximately 19 % of Italy's surface.

Overall, the Map of the Vegetation Series of Italy confirms the potential for forest vegetation for over 90 % of the national territory (current forest cover is greater than 30 %), and highlights an extraordinary diversity of vegetation types. It depicts 240 vegetation series (sigmeta) and 39 geosigmeta, classified in the legend according to climatic region, bioclimatic type and geographic sector, and characterised according to their Latin name and geographical distribution, ecology and physiognomy. The wealth of available information is highlighted by the fact that beech forests fall into 41 different vegetation series, and deciduous oak woodlands into 85. No vegetation series are found in both the Alps and the rest of the peninsula; different vegetation series have been found under the same ecological conditions in both the central and southern Apennines. The regions with the highest proportions of endemic plants are Sardinia and Sicily (in total, 58 exclusive species).

Since the vegetation series map can be used to assess both landscape and vegetation heterogeneity, and to compare them with land use in terms of dynamics and potentiality, it is a tool that could play an important role. It could be used to conserve natural resources, provide the scientific foundations for a strategy to adapt to climate change, and act as a reference point for the planning and management of European landscapes.

The map of vegetation series is also essential for detecting sites with maximum-potential heterogeneity, and for identifying the varying degrees of human activity–induced disturbance that affects areas far from their maximum potential — this applies in particular to restoration and requalification projects.

Comparing the land cover map to a map of the vegetation series of a territory provides some information on its state of conservation. However, maps of vegetation series can prove even more useful for assessing the state of conservation when pattern analysis on the vegetation patches belonging to the same vegetation series is performed.

Mapping vegetation series in Italy is a starting point for assessing present and potential heterogeneity of given real vegetation, which represents the reference model for assessing the ecological functionality and the state of conservation of a territory.

7.6 Latvia

7.6.1 History

Vegetation studies in Latvia started at the beginning of the 20th century, and K. R. Kupffer (1872–1935) produced the first vegetation map in Latvia for Moricsala Island (Kupffer, 1931). The first researchers described vegetation according to its physiognomy and dominant plant species. However, floristic investigations prevailed during that period. After the Second World War, botanists in Latvia started to use the Russian school of dominants (e.g. Tsinzerling, 1938; Lavrenko, 1950; and Alexandrova, 1973) in vegetation studies. Their work was mainly devoted to the description of plant communities in mires (e.g. Tabaka, 1960), grasslands (e.g. Sabardina, 1957) and forests (e.g. Sakss, 1955). In 1959, country-wide mapping of vegetation started in Latvia under the auspices of the Institute of Biology alongside other large-scale vegetation mapping in other parts of former USSR.

The mapping unit was a group of associations and there were 50 mapping units (Tabaka and Birkmane, 1970). Unfortunately, the main output, a 1:200 000 vegetation map, remained unpublished for political reasons. The main aim of this country-wide vegetation mapping was purely scientific. Vegetation maps were also created for particular protected nature areas, and detailed vegetation maps (e.g. 1:10 000) for some areas exist. At the same time, numerous botanical expeditions and analyses of climate and geology resulted in the delineation of eight geobotanical regions in Latvia (Kabucis, 1995). Moreover, long-term collaboration of Latvian, Lithuanian and Estonian botanists resulted in the joint publication on the flora of the Baltic countries with a description of geobotanical regions in all three countries (Laasimer et al., 1993; Kuusk et al., 1996; Kuusk et al., 2003). In the 1980s, Prof. M. Laiviņš started to use the Braun-Blanquet approach (Braun-Blanquet, 1964) in vegetation studies (Laiviņš, 1984), and many other researchers followed this approach after 1990.

Meanwhile, forest stand classification and mapping has a long history, going back to the beginning of 20th century. The forest-growth condition types are determined by stand productivity and ecological and biological attributes, including vascular plant and bryophyte species. A total of 23 growth condition forest-types are distinguished and used for forest mapping for forest management purposes (Bušs, 1997). However, the forest vegetation syntaxa distinguished in Latvia correlate poorly with forest stand classification units (Priedītis, 1997).

7.6.2 Recent developments

Recently, the first and the only large-scale vegetation mapping in Latvia was carried out between 2000 and 2002, when a survey and inventory of biologically valuable semi-natural grasslands covered almost all Latvia. Vascular plant species cover in three categories was evaluated, and each mapping unit was assigned to one of the grassland habitat types of Latvia or a complex (Kabucis et al., 2003), which in turn can be assigned to semi-natural grassland associations. A vegetation map using phytosociological units was created for the forests in Ķemeri National Park (Priedītis, 1995). There are also some vegetation structure maps created using satellite imagery in Latvia, e.g. for Engure Lake in the Engure Nature Park (Auniņš et al., 2000) and a habitat map for the Gauja National Park (Auniņš, 2001). Maps of mire micro-landscapes in 12 protected mires were also prepared (Namatēva, 2012). Protected areas have always been the most common target for any kind of habitat mapping since the beginning of the 20th century. Spatial scale and mapping units varies depending on the size of protected nature area and the aims of the study.

Since Latvia started the process of joining the EU in 2000, a great deal of attention has been given to the identification of Annex I habitats of the Habitats Directive, and to mapping these habitat types within Natura 2000 areas. Additionally, researchers from the Faculty of Biology of University of Latvia have prepared a map of Annex I habitats in a 300 m zone along the shoreline of Latvia (Life-Nature project 'Piekrastes biotopu aizsardzība un apsaimniekošana Latvijā', 2006).

At the moment, there is an urgent need for country-wide mapping of Annex I habitat types in Latvia, and this activity is included in almost all relevant documents related to biodiversity conservation. Traditional vegetation mapping solely based on units defined by phytosociology seems to be overlooked, despite many Annex I habitat types being based on syntaxa.

7.7 Lithuania

7.7.1 History

The history of vegetation surveys in Lithuania, as elsewhere in the Baltic States, is complex; the dramatic political upheavals of the 20th century brought about distinct changes in methodologies used by vegetation scientists.

Lithuania's geographic position resulted in influence from the ideas and methods of both Nordic countries (the Uppsala School of Phytosociology) and of central Europe (the Zürich-Montpellier or Braun-Blanquet approach). However, these ideas were only applied to evaluations of plant community diversity (e.g. Regelis, 1926; Dagys, 1933; Žvironaitė, 1934; Mowszowicz, 1938) and no vegetation maps were produced, except the map of the Kamanos mire complex prepared according to the Nordic phytosociological tradition (Brundza, 1937).

After the Second World War, Lithuanian vegetation science was heavily influenced by the Russian Geobotanical School. Numerous vegetation units were defined mostly according to the dominant plant species, but this approach proposed no effective solutions for vegetation mapping. Of particular interest are the Lithuanian cadastral forest maps compiled following the principles of Russian Biogeocoenotic School (V. Sukatchev), where site types, dominant tree species, landscape elements and timber economic characteristics were the main unit defining factors (Karazija, 1988). These cadastral maps covered some 33 % of the country's area and were updated every 10 years.

During that period, a large-scale vegetation map (1:1 000 000) on the landscape level with some elements of reconstructive vegetation (PNV) was published (Natkevičaitė–Ivanauskienė, 1981).

7.7.2 Recent developments

Recent changes in vegetation mapping are related to the need to implement the EU Habitats Directive before joining the EU in 2004. This work resulted in the mapping of semi-natural grassland vegetation at the level of phytosociological alliances (19 mapping units with 54 000 hectares mapped), which was completed in 2005 (Rašomavičius et al., 2006). It was followed by continued habitat-mapping projects that should result in distribution maps for all Annex I habitat types, covering the entire country (Rašomavičius, 2012).

7.8 The Nordic region: Denmark, Finland, Iceland, Norway and Sweden

7.8.1 History

Countries within the Nordic region, including Denmark, Finland, Iceland, Norway and Sweden have many related practices regarding vegetation mapping. Early vegetation mapping within the Nordic region was based on units from phytosociological works that began in the second part of the 19th century, but gained momentum in the first part of the 20th century (e.g. von Post, 1851; Cajander, 1909; Raunkiær, 1910; Du Rietz, 1921; Fries, 1913; and Nordhagen, 1936). Due in part to the low number of plant species and the lack of clear indicator species, an approach known as the Nordic or Uppsala school of phytosociology developed (e.g. Diekmann, 1995; Lawesson et al., 1997). The first vegetation maps based on units defined by phytosociology were produced at different times, in Norway, for example, in 1937 (Mork and Heiberg), and in Iceland in 1957 (Johannesson and Thorsteinsson). In Iceland, vegetation mapping was under way in the 1960s, whereas Norway and Sweden increased their efforts mainly from the mid 1970s onwards (Ihse and Wastenson, 1975; Ihse, 1994; Andersson, 2010; Rekdal and Bryn, 2010).

7.8.2 *Recent developments*

Vegetation mapping in the Nordic region has been directed mainly towards two spatial scales: a large scale for mapping of detailed vegetation units closely related to phytosociology (e.g. Påhlsson, 1994; and Fremstad, 1997), and a small scale for survey mapping focused more on physiognomy that can be recognised through aerial photos (Ihse and Wastenson, 1975; Andersson, 2010; Gudjonsson, 2010; Rekdal and Bryn, 2010). In general, most of the vegetation maps in the Nordic countries have been produced using the second approach, using map scales ranging from 1:20 000 to 1:80 000. In Sweden, mapping started in the mountains and was developed further to cover parts of the lowland. Today, vegetation maps cover approximately 53 % of Sweden, but production has ceased and new methods using remote sensing data including satellite imagery, digital aerial photos and LiDAR, are currently being developed (Olsson et al., 2011).

During the last decade or so, the mapping effort within most of the Nordic countries has slowly drifted from traditional vegetation mapping towards mapping of 'nature types', e.g. natural habitats in Natura 2000 sites (Allard and Skånes, 2010). Finland, Sweden and Denmark are members of the EU and therefore need maps of Annex I habitats to implement the Habitats Directive, whereas Norway and Iceland (non-EU) have started their own projects of mapping nature types (e.g. Halvorsen et al., 2009) and habitat types based on vegetation maps (e.g. Magnusson et al., 2009). This drift has been caused partly by the need to map units that cannot be defined by vegetation (e.g. cold-water coral reefs), partly by the need to include more details and descriptions than those usually registered through vegetation mapping, and partly owing to legal frameworks related to the mapping units.

7.9 Slovakia (including former Czechoslovakia)

7.9.1 *History*

Mapping of vegetation in Czechoslovakia has a long history, starting with mapping of the distribution of woody plants. Geobotanical mapping started just after the Second World War in 1947, but official mapping began later in 1954 under the coordination of academic institutions. At first there was considerable work on theoretical concepts and methodologies of vegetation mapping. Authors such as R. Mikyška, R. Neuhäusl, J. Moravec and other colleagues developed concepts which were slightly different from the concept of potential vegetation mapping (Neuhäusl, 1963). The book *Geobotanical map of Czechoslovakia* was published in 1968; its first volume is devoted to Bohemia and Moravia, and the vegetation is illustrated on 21 maps at a 1:200 000 scale (Mikyška et al., 1968) although the field survey was at 1:50 000. The authors recognised 19 mapping units based on the Zürich-Montpellier approach, although they are not all at the same hierarchical level — some represent classes, others are more narrowly defined, mostly alliances. The second volume, devoted to Slovakia, was published in 1987 and the vegetation is illustrated on 12 maps at the same scale. The total number of mapping units was 41, with the most variation in the Carpathian Mountains and the Pannonian basin (Michalko et al., 1987). The principal experts were D. Magic, J. Berta and team leader J. Michalko.

The vegetation map of Slovakia clearly belongs to the category of reconstructive maps. Unlike the mapping of contemporaneous PNV according to Tüxen (1956), reconstructive mapping aims to display plant cover relating to the climax vegetation of the late postglacial age, prior to any human impact. The two concepts are almost identical in an unchanged landscape, while major differences occur when the habitats conditions have been irreversibly changed by man (Moravec, 1998).

7.9.2 *Recent developments*

Vegetation mapping in recent years has mostly focused on actual vegetation. Several projects were organised from 1998 onwards to map both distribution and state of different habitat types.

Except for the national grassland inventory (see Box 6.8), inventories of peatland habitats (at a scale of 1:10 000) and of non-forest Natura 2000 habitats (at a scale of 1:25 000) were organised by DAPHNE — Institute of Applied Ecology and the Slovak State Nature Conservancy. Both inventories were related to the designation of the Natura 2000 network. The results were not published, but they are incorporated into a GIS which is widely used by conservation agencies.

The latest inventory project was a map of old-growth forests (2009–2010) organised by the NGO FSC-Slovakia. All old-growth forests larger than 25 ha were mapped and recorded in a database. This information is available at http://www.pralesy.sk.

7.10 Spain

After the concepts of vegetation succession were introduced from the Braun-Blanquet school to Spain in the late 1950s and 1960s, S. Rivas-Martínez was the first to define the PNV types in Spain. In the late 1970s, the Instituto para la Conservación de la Naturaleza (Spanish Institute for Nature Conservancy (ICONA)) commissioned a project to map the vegetation series of Spain at a 1:400 000 scale. The fieldwork was completed in 1981 and was published in 1987. This map and the accompanying legend had an enormous influence on the further development of vegetation studies in Spain and on the general assumptions of conservation policy by different administrations. The legend is a book containing an outline of the general conditions, bioclimatology and biogeography of the country, as well as descriptions of the vegetation series. The maps show nearly 100 units which represent a synthesis of the large diversity of Spanish terrestrial ecosystems. One of this work's main contributions was introducing the concept of dynamic vegetation to managers of ecosystems, and making a diagnosis for the entire country (not only well-conserved areas but also degraded areas, with an ecological reference of naturalness for any piece of land). The map gave Spanish nature conservation a frame for ecological description of the entire country. That map is being replaced by a new edition due to be completed soon, with more represented units and a larger scale (1:250 000); the legend has been already published (Rivas-Martínez, 2007 and 2011). LIFE also funded a project to map habitats in order to help implement the Habitats Directive (see Box 5.3 for further details).

At regional level, many Spanish autonomous communities conducted habitat and/or vegetation mapping projects; see case studies in Chapter 4 for further information.

7.11 United Kingdom

The earliest systematic attempts to map vegetation in the United Kingdom accompanied botanical surveys of parts of Scotland (Smith, 1900a and 1900b; Smith, 1904–1905), Yorkshire (Smith and Moss, 1903; Smith and Rankin, 1903), Somerset (Moss, 1906) and Derbyshire (Moss, 1913), but hopes that these might form the basis of a national mapping programme were frustrated by the First World War. Although vegetation maps of many smaller localities, including large areas of the Scottish uplands, were produced over the next 70 years using different legends and conventions, it was not until the advent of the National Vegetation Classification (Rodwell, 1991–2000) that a single comprehensive phytosociological typology became available for mapping. Much of the United Kingdom, including the uplands (e.g. Averis and Averis, 2003), woodlands (Kirby, 2001), coastal dune systems (e.g. Dargie, 1998) and lowland grasslands (e.g. Jefferson and Roberstson, 1996) have since been mapped using the NVC, though without national coordination of scale, graphic conventions or software platforms.

Various kinds of habitat mapping for the United Kingdom can also be cross-related to some extent to broad vegetation types or the NVC. Phase I Habitat Survey (JNCC, 2010) has been widely used for field-by-field survey of the lowlands and in conjunction with remote sensing for upland regions. The quality and availability of maps are variable, but a good example of the value of such data has recently been published for Wales (Blackstock et al., 2010). Broader habitat categories, derived from the UK Biodiversity Action Plan, provide the typology for the UK Land Cover Map produced by the Centre for Ecology & Hydrology on behalf of the UK Countryside Survey partnership in 1990, 2000 and 2011 (see http://www.ceh.ac.uk). Derived from satellite imagery and digital map data, it provides continuous cover across the country at 25-metre resolution.

8 Conclusion

Vegetation mapping has a long history and remains a very active discipline in Europe: it is at the dynamic interface between vegetation science and geography, academic research and applied conservation. However, mapping large areas such as entire countries or regions remains a challenge where time and resources are recurrent constraints and quality a permanent objective.

Despite the diversity of large-area vegetation mapping encountered in our survey, each project has addressed similar strategic questions. The starting point for each project is to define objectives; there are generally one or two requirements at the inception of a project corresponding to the project owners' activities or commitments. Often, secondary objectives are linked to the interests of other stakeholders (e.g. academic applications, spatial planning and forestry). Nevertheless, it is necessary to define a hierarchy for the different objectives, in order to design a project and a mapping methodology compatible with the time and resources available (human, material and financial).

Therefore, different factors must be balanced to obtain the desired results: geographical precision vs wide coverage, detailed vegetation communities vs general habitat categories, all habitat types vs only protected habitat types, field mapping vs remote sensing. The project duration also needs careful consideration: projects which do not allow sufficient time are likely to encounter quality issues, whereas those with a long duration may have problems reaching completion.

The quality of the final product depends on a combination of topographical (i.e. spatial) and typological (i.e. thematic) accuracy. For area-wide programmes that require a certain level of homogeneity, it is necessary to implement standardised mapping methodologies. This includes an explicit typology with adapted diagnosis tools (e.g. decision rules, determination keys and interpretation guides). Moreover, if the results are to be comparable in space and time, it is recommended that the project produces simple but reliable and consistent information rather than detailed but heterogeneous data.

In order to assess quality, map validation can be qualitative or quantitative. Qualitative assessment, the most frequently used approach, is usually carried out by regional and national experts. However, quantitative validation is more reliable to measure accuracy. It must be based on sound statistical analyses and appropriate sampling plans.

Finally, continuing improvements, both technical (e.g. GIS, remote sensing, modelling, data management and statistical analysis) and methodological (e.g. landscape and dynamic approaches, and habitat monitoring) provide encouraging perspectives for the future.

The wide range of uses and applications presented illustrate how maps can serve as multipurpose tools for implementing biodiversity policies.

List of figures, tables, boxes and maps

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List of organisations

Alterra	Wageningen University and Research Centre, Alterra
AOPK ČR	Agentura ochrany přírody a krajiny České republiky (Nature Conservation Agency of the Czech Republic)
BfN	Bundesamt für Naturschutz (German Federal Agency for Nature Conservation)
BILAS	Botanikos institutas, Floros ir geobotanikos laboratorija (Lithuanian Institute of Botany, Laboratory of Flora and Geobotany)
CAFF	Conservation of Arctic Flora and Fauna
CBNA	Conservatoire Botanique National Alpin (Alpine National Botanical Conservancy)
CEC	Commission of the European Communities
CIRBFEP	Sapienza Università di Roma, Facoltà di Scienze Matematiche, Fisiche e Naturali, Dipartimento di Biologia Vegetale — Centro interuniversitario di ricerca biodiversità fitosociologica ed ecologia del paesaggio (Sapienza University of Rome, Faculty of Mathematical, Physical and Natural Sciences, Department of Plant Biology — Interuniversity Research Centre 'Biodiversity, Plant Sociology and Landscape Ecology')
CKFF	Center za kartografijo favne in flore (Centre for Cartography of Fauna and Flora)
CNRS	Centre national de la Recherche scientifique (French National Centre for Scientific Research)
CoE	Council of Europe
DAPHNE	DAPHNE — Inštitút Aplikovanej Ekológie (DAPHNE — Institute of Applied Ecology)
EEA	European Environment Agency
EEC	European Economic Community
Eionet	European Environment Information and Observation Network
ETC/BD	European Topic Centre on Biological Diversity
EU	European Union
EVS	European Vegetation Survey
FAO	Food and Agriculture Organization
FCBN	Fédération des Conservatoires Botaniques Nationaux (Federation of National Botanical Conservancies)
FSC	Forest Stewardship Council
GEOVEG	Universitat de Barcelona, Facultat de Biologia, Dept de Biologia Vegetal — Grup de Recerca de Geobotànica i Cartografia de la Vegetació (University of Barcelona, Faculty of Biology, Department of Plant Biology — Research Group of Geobotany and Vegetation Mapping)
HELCOM	Helsinki Commission
IAVS	International Association for Vegetation Science

IB/BAS (ИБ/БАН)	Българската академия на науките, Институтът по ботаника (Botanical Institute, Bulgarian Academy of Science)
ICONA	Instituto para la Conservación de la Naturaleza (Spanish Institute for Nature Conservation)
IGN	Institut national de l'information géographique et forestière (French National Institute of the Geographic and Forest Information)
IMBE	Institut méditerranéen de biodiversité et d'écologie marine et continentale: CNRS-INEE — IRD -Aix Marseille Université — Université d'Avignon — Institut Pytheas, Département Processus fonctionnels et Valorisation de la Biodiversité, (Mediterrean Institute of biodiversity and marine and continental ecology: Institute of ecology and environmetn of the Scientifific Research National Centre — Research Institute for Development — Aix-Marseille University — Avignon University, Department of functional processes and biodiversity valorisation)
INBO	Instituut voor Natuur- en Bosonderzoek (Flemish Research Institute for Nature and Forest)
IRSTEA	Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture (French National Research Institute on Sciences and Technologies for the Environment and Agricolture)
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale (Italian National Institute for Environmental Protection and Research)
ISPRS	International Society for Photogrammetry and Remote Sensing
ISTHME Univ. St Etienne	Université Jean Monnet Saint-Etienne, Département scientifique pédagogique et technologique 6 Sciences Humaines et Humanités (SHS), Unité de recherche Image Société Territoire Homme Mémoire Environnement (St Etienne University 'Jean Monnet', Scientific, pedagogic and technologic department 6: Human Sciences and Humanities, Research Unit Image, Society, Territory, Man, Memory, Environnement)
JNCC	Joint Nature Conservation Committee
JRC	Joint Research Centre
KNNV	Koninklijke Nederlandse Natuurhistorische Vereniging (Royal Dutch Society for Natural History)
LDF	Latvijas Dabas Fonds (Latvian Fund for Nature)
MEDDE	Ministère de l'Ecologie, du Développement durable et de l'Energie (French Ministry of Ecology, Sustainable develpment and Energy)
MNHN	Muséum national d'Histoire naturelle (French National Museum of Natural History)
MTA ÖBKI	Magyar Tudományos Akadémia, Ökológiai és Botanikai Intézet (Hungarian Academy of Sciences, Institute of Ecology and Botany)
NHM, Skog og landskap	Naturhistorisk museum, Norsk institutt for skog og landskap (Norvegian Museum of Natural History, Norwegian Forest and Landscape Institute)
NOAA	National Oceanic and Atmospheric Administration
NÍ	Náttúrufræðistofnun Íslands (Icelandic Institute of Natural History)
NRC	National Reference Centres
ONF	Office National des Forêts (French National Forest Office)
OSPAR	Commission of the Oslo and Paris Conventions

PřF MU	Masarykova univerzita, Přírodovědecká fakulta, Ústav botaniky a zoologie (Masaryk University, Faculty of Science, Department of Botany and Zoology)
SAV	Slovenská Akadémia Vied, Botanický ústav (Slovakian Academy of Sciences, Institute of Botany)
SBI	Società Botanica Italiana (Italian Botanical Society)
SISV	Società Italiana di Scienze della Vegetazione (Italian Society for Vegetation Science)
SPN — MNHN	Muséum national d'Histoire naturelle, Service du Patrimoine Naturel (French National Natural History Museum, Natural Heritage Service)
SPW	Service Public de Wallonie (Public Service of Wallonia)
UBA	Umweltbundesamt (Austrian Federal Environment Agency)
UNICAM	Università di Camerino, Scuola di Scienze Ambientali (ex. Dipartimento di Scienze Ambientali) (University of Camerino, School of Environmental Sciences (ex. Department of Environmental Sciences))
Univ. Perugia	Università degli Studi di Perugia, Facoltà di Agraria, Dip. Biologia Applicata, Sez. Biologia vegetale e Geobotanica (University of Perugia, Faculty of agricolture, Department of Applied Biology section Plant Biology and Geobotany)
Univ. Stockholm	Stockholms universitet, Naturvetenskapliga fakulteten — Sektionen för geo- och miljövetenskaper, Institutionen för naturgeografi och kvartärgeologi (Stockholm University, Faculty of Science — Earth and Environmental Sciences Section, Department of Physical Geography and Quaternary Geology)
Univ. Turun	Turun yliopisto, Matemaattis-luonnontieteellinen tiedekunta, Maantieteen ja geologian laitos (University of Turku, Faculty of Mathematics and Natural Sciences, Department of Geography and Geology)
Univ. W-Greece	Πανεπιστήμιο Δυτικής Ελλάδας, Τμήμα Διαχείρισης Περιβάλλοντος και Φυσικών Πόρων (University of Western Greece, Department of Environmental and Natural Resources Management)
UPV/EHU	Universidad del País Vasco, Departamento de Biología Vegetal y Ecología/Euskal Herriko Unibertsitatea,Landareen Biologia eta Ekologia Sailak (University of the Basque Country, Department of Plant Biology and Ecology)
ZRC SAZU	Znanstvenoraziskovalni center Slovenske akademije znanosti in umetnosti, Biološki inštitut Jovana Hadžija (Research Centre of the Slovenian Academy of Sciences and Arts, Jovan Hadži Institute of Biology)

List of acronyms

3D	Three-dimensional space
3G	Third Generation (of mobile telecommunications technology)
AE	Agri-environmental
AirSAR	Airborne Synthetic Aperture Radar
anArchive	an Archive for Botanical Data
ÁNÉR	Általános Nemzeti Élőhely-osztályozási Rendszer (Hungarian General National Habitat Classification System)
AOO	Area of occupancy
ASTER	Advanced spaceborne thermal emission and reflection radiometer
AURELHY	Analyse Utilisant le Relief pour l›Hydrométéorologie (Analysis using the relief for Hydrometeorology)
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
BioHab	A framework for the coordination of biodiversity and habitats
CAFF	Conservation of Arctic Flora and Fauna
CAP	Common Agricultural Policy
CarHAB	Cartographie des Habitats (Habitat mapping of France)
CASI	Compact Airborne Spectrographic Imager
CAVM	Circumpolar Arctic Vegetation Map
CBN	Conservatoire Botanique National
CD	Conservation degree
CFG	CAFF Flora Group
CNRS	Centre national de la recherche scientifique
CHC50	Map of Catalan Habitats (1:50 000)
CoE	Council of Europe
Corine	Coordination of Information on the Environment
DEM	Digital elevation model
DTM	Digital terrain model
EBONE	European Biodiversity Observation Network (EU-funded research project)
EEA	European Environment Agency
EIA	Environmental impact assessment
EO	Earth Observation
ETM+	Enhanced Thematic Mapper Plus
ETRS	European Terrestrial Reference System
EU	European Union
EUNIS	European Nature Information System
EuroVeg Checklist	European Vegetation Checklist
EVA	European Vegetation Archive
EVI	Enhanced Vegetation Index
EVS	European Vegetation Survey
FYR	Former Yugoslav Republic

GDR	German Democratic Republic
GEF	Global Environmental Facility
GHC	Global Habitat Classification
GI	Green infrastructure
GIS	Geographic Information System
GIVD	Global Index of Vegetation-Plot Databases
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUID	Global Unified Identifier
HCI	Habitats of Community Interest
HNV	High Nature Value
HR	High resolution
HyMap	Hyperspectral Mapper
IAVS	International Association for Vegetation Science
ID	Identifier
IEE	Initial Environmental Examination (or Evaluation)
IGN	Institut Géographique National
INSPIRE	Infrastructure for Spatial Information in the European Community (EU Directive)
INTERREG	Interregional co-operation EU programme
IRC	Infrared Colour
IRS	Indian Remote Sensing satellites
IT	Information technology
JRC	Joint Research Centre
LAEA	Lambert Azimuthal Equal Area
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LiDAR	Laser Imaging Detection and Ranging
MAES	Mapping and Assessment of Ecosystem Services
MÉTA	Magyarország Élőhelyeinek Térképi Adatbázisa (Database and Map of Hungarian Habitats)
MIR	Medium Infrared
MNHN	Muséum national d'Histoire naturelle
MODIS	Moderate Resolution Imaging Spectroradiometer
N2000	Natura 2000
NDVI	Normalised Difference of Vegetation Index
NGO	Non-governmental organisations
NIR	Near Infrared
NRC	National Reference Centre
NVC	National Vegetation Classification
OGC	Open Geospatial Consortium
PEEN	Pan-European Ecological Network
PNV	potential natural vegetation
Radar	Radio Detection and Ranging
RS	Remote Sensing
SAR	Synthetic Aperture Radars
SCI	Site of Community Importance
SDM	Species distribution model
SEA	Strategic Environmental Assessment
SHS	Sciences Humaines et Humanités
SINP	Système d'Information sur la Nature et les Paysages (Information System on Nature and Landscapes)

SPN	Service du Patrimoine naturel
SPOT	Satellite pour l'Observation de la Terre (System for Earth Observation)
SQL	Structured Query Language
SRTM	Shuttle Radar Topography Mission
SynBioSys	Syntaxonomisch Biologisch Systeem (Syntaxonomic Biologic System)
VegItaly	Vegetation of Italy
VHR	Very High Resolution
VIS	Visible
VMC50	Vegetation Map of Catalonia (1:50 000)

Annex 1 List of the 65 projects selected for the survey

Country	Project title (original)	Project title (English)
Albania	Inventarizimi kombëtar i pyjeve të Shqiperisë	Albanian National Forests Inventory
Albania	Karte der Waldstufen in Albanien, 1:1 000 000 (Markgraf, F., 1949)	Map of forest stages in Albania — 1:1 000 000
Albania	Map of the Natural Vegetation of Europe:Albanien, 1:500 000 [manuscript map]	Map of the Natural Vegetation of Europe:Albania — 1:500 000 [manuscript map]
Andorra	El mapa d'habitats d'Andorrea	Habitat mapping Andorra
Austria	Austrian-wide project to map the Annex I priority habitat types	Austrian-wide project to map the Annex I priority habitat types
Austria	Die natürliche Pflanzendecke Österreichs	The natural vegetation cover in Austria
Austria	Karte der aktuellen Vegetation von Tirol 1:100 000	Map of actual vegetation of Tyrol — 1:100 0000
Austria	Mapping of Annex I habitats of the FFH-directive	Mapping of Annex I habitats of the FFH-directive
Belgium	Carte de la végétation de la Belgique 1956–1968	Vegetation map of Belgium (1956–1969)
Belgium	Carte d'évaluation biologique	Biological evaluation maps of Belgium (Wallonia)
Belgium	De Biologische Waarderingskaart versie 1	Biological evaluation maps of Belgium (Flanders) version 1
Belgium	De Biologische Waarderingskaart versie 2	Biological evaluation maps of Belgium (Flanders) version 2
Bulgaria	Mapping and Identification of Conservation Status of Natural Habitats and Species	Mapping and identification of conservation status of natural habitats and species
Bulgaria	The vegetation of Bulgaria. 1/600 000	The vegetation of Bulgaria — 1:600 000
Croatia	Karta Šumskih Zajednica Republike Hrvatske	Vegetation Map of Forest Communities of Croatia
Croatia	Kartiranje staništa Republike Hrvatske (2000–2004)	Habitat mapping of Croatia
Croatia	Vegetation map of Yugoslavia (Croatia)	Vegetation map of Yugoslavia (Croatia)
Czech Republic	Aktualizace vrstvy mapování bitopů	Habitat mapping layer update
Czech Republic	Mapování biotopů v České republice	Habitat mapping in the Czech Republic
Czech Republic	PNV: vegetation map of Czech Republic	PNV: vegetation map of Czech Republic
Czech Republic	Reconstructed Natural Vegetation of Czechoslovakia	Reconstructed Natural Vegetation of Czechoslovakia
Europe	Carte de la végétation naturelle de la communauté européenne	Natural Vegetation Map of the European Communities and the Council of Europe (from Corine) from UNEP/GRID-Geneva
Europe	Carte des végétations naturelles (potentielles) d'Europe	Map of the Natural Vegetation of Europe — 1:2 500 000
Finland	Valtakunnallinen harjujensuojelu-ohjelma	National esker protection programme
France	Carte de la végétation de la France du CNRS ('carte Gaussen')	Vegetation map of France ('Gaussen map')
Germany	Biotopkataster Rheinland-Pfalz	Rhineland-Palatinate Biotope cadaster
Germany	Vegetationskarte der Bundesrepublik Deutschland — Potentielle natürliche Vegetation	Vegetation map of the Federal Republic of Germany - Potential natural vegetation
Greece	Identification, description and mapping of habitat types in sites important for nature conservation in Greece	Identification, description and mapping of habitat types in sites important for nature conservation in Greece
Hungary	Actual habitat map of the Duna-Tisza region	Actual habitat map of the Duna-Tisza region
Hungary	MÉTA program	MÉTA program
Hungary	National inventory of semi-natural grassland	National inventory of semi-natural grassland
Hungary	Potential vegetation Zólyomi 1989	Potential vegetation Zólyomi 1989
Hungary	Reconstructed vegetation Zólyomi	Reconstructed vegetation Zólyomi
Italy	Carta della Natura 1:50 000	Nature map of Italy (Habitat mapping) 1:50 000
Italy	Carta della vegetazione naturale potenziale d'Italia	Potential natural vegetation map of Italy
Italy	Carta delle Serie di Vegetazione d'Italia	Map of vegetation series of Italy
Italy	Carta delle serie di vegetazione della Sardegna 1:350 000	Map of vegetation series of Sardinia — 1:350 000
Montenegro	Vegetation map of Yugoslavia (Montenegro)	Vegetation map of Yugoslavia (Montenegro)

Country	Project title (original)	Project title (English)
Netherlands	Vegetation map of the Netherlands (ecotopes and types of actual and potential natural vegetation)	Vegetation map of the Netherlands (ecotopes and types of actual and potential natural vegetation)
Norway	Vegetasjonskartlegging i Norge	Vegetation Mapping in Norway
Poland	Potencjalna roślinność naturalna Polski	Potential natural vegetation of Poland
Poland	Potential natural vegetation of Poland (Potencjalna roślinność naturalna Polski)	Potential natural vegetation of Poland
Portugal	Map of Natural Potential Vegetation (Vegetation Series) of mainland Portugal	Map of Natural Potential Vegetation (Vegetation Series) of mainland Portugal
Romania	Karta Vegetaţia României 1:2.500.000	Vegetation map of Romania — 1:2 500 000
Romania	National inventory of semi-natural grassland	National inventory of semi-natural grassland
Slovakia	National inventory of semi-natural grassland	National inventory of semi-natural grassland
Slovakia	RNV: vegetation map of Czechoslovakia (part: Slovakia)	RNV: vegetation map of Czechoslovakia (part: Slovakia)
Slovenia	Gozdnovegetacijska karta Slovenije	Forest vegetation map of Slovenia
Slovenia	Vegetacijska karta gozdnih združb	Vegetation map of forest communities of Slovenia
Slovenia	Vegetation map of Yugoslavia (Slovenia)	Vegetation map of Yugoslavia (Slovenia)
Spain	Atlas y Manual de Interpretación de los Hábitat Españoles	Atlas and Interpretation Manual of Spanish Habitats
Spain	Cartografía de Vegetación y usos del suelo de la CAPV (MV2005)	Vegetation and land use mapping of the Basque country (EUNIS 2005)
Spain	Cartografia dels hàbitats de Catalunya (CHC 50)	Habitat mapping of Catalonia
Spain	Cartografía e inventariación de los tipos de hábitats de la Directiva 92/43/CEE en España	Mapping and inventory of Annex I habitats of the FFH-directive in Spain
Spain	Cartografía Temática Ambiental del Principado de Asturias. Mapa de Vegetación	Environmental Thematic Cartography of Asturia. Vegetation Map
Spain	Hábitats de la Comunidad Valenciana	Habitats of the Valencian Community
Spain	Mapa de Hábitats de Aragon	Map of Habitats of Aragon
Spain	Mapa de la vegetació potencial de Catalunya 1:250 000	Potential vegetation map of Catalonia 1:250 000
Spain	Mapa de Series de Vegetación de Navarra 1:200.000 (on line 1:50.000)	Map of the vegetation series of Navarre
Spain	Mapa de series vegetación de la Comunidad Autónoma del País Vasco (series de vegetación a escala 1:50 000)	Map of the vegetation series of Basque Country
Spain	Mapa de vegetació de Catalunya 1:50 000	Vegetation map of Catalonia — 1:50 000
Spain	Mapa de Vegetación Potencial de España	Potential vegetation map of Spain
Spain	Mapa de Vegetación Potencial de Navarra 1:25 000	Potential vegetation map of Navarra 1:25 000
Sweden	Basinventering av skyddade områden och Natura 2000-områden	Baseline mapping of Natura 2000 areas and other areas under nature protection
Switzerland	Carte de la distribution potentielle des milieux naturels de Suisse	Map the potential distribution of natural habitats in Switzerland

Annex 2 The questionnaire adressed to 40 European countries

QUESTIONNAIRE	
Country (FR)	
Country (EN)	
Project_title (original)	
Project_title (English)	
Administrative level	CLASS
Territory area (km²)	
Extend of the map	TEXT
National territory area (km²)	
Area_mapped (km²)	
% of the area mapped - MIN/MAX.	
EU_27	YES/NO
State of progress	CLASS
Project starting date	
Mapping starting date	
Project completion date	
Main project owner (Type)	
Project owner	
Project manager (name)	
Main project manager (type)	
Other active stakeholders (action pilot)	
Type of fieldwork operators	
Other type of fieldwork operators	
Project partners	
Governance modalities	
National_methodological_harmonization	YES/NO
Budget	
European funding	YES/NO
National funding	YES/NO
Regional funding	YES/NO
Application: DFFH	YES/NO
Application: Vegetation Red lists	YES/NO
Application: Landscape planning	YES/NO
Application: Protected areas managment	YES/NO
Application: Protected areas strategy (KBA...)	YES/NO
Application: Habitat monitoring	YES/NO
Application: Climate change monitoring	YES/NO
Interoperability with other territories	YES/NO
Partnership with european institutions	YES/NO
Partnership with international institutions	YES/NO
Other applications of the project	
Publications, reports	
Language of the publication	

Typology_category	1-4
Typology (phytosociology or with correspondence to phytosociology)	YES/NO
Area >5.000km² OR >50% of the national territory	YES/NO
Scale (Category)	
Optimal_use_scale	
Published_scale_largest	
Published_scale_smallest	
Field_Mapping_scale__largest	
Field_Mapping_scale_smallest	
Minimum mapped area (ha)	
Type of objects mapped	
Remark Type of objects	
Anthrogenic vegetation	YES/NO
Habitat quality	
Monitoring modalities	
Typology	TEXT
Typological level	
Number_of_classes_MIN.	
Number_of_classes_MAX.	
Typological correspondences: FFH/EUR 25	1-2-3
Typological correspondences: Corine Biotopes	1-2-3
Typological correspondences: EUNIS	1-2-3
Typological correspondences: Others	TEXT
Mosaic mapping	YES/NO
Actual vegetation	YES/NO
Potential_natural_vegetation	YES/NO
Methodological documents	
Reference Methodological documents	
Interpretation manual for habitat types	
Test area	YES/NO
Update	
Fieldwork	YES/NO
Floristic relevés	
type of Floristic relevés	TEXT
Human resources (for fieldwork)	
Human resources (for fieldwork)	TEXT
Field devices	TEXT
Specific training	TEXT
Reference Interpretation manual for habitat types	YES/NO
Remote sensing : aerial photography	YES/NO/ POSSIBLE
Remote sensing : satellite/sensor images	CLASS
Satellite image processing	CLASS
Type of remote sensing : satellite/sensor images	
Mono or multi-temporal data	Nb of botanists involved
Modelling	Nb man-days
Base maps	
Environmental data used	YES/NO

Polygon segmentation	
Existing vegetation maps	
Other sources used	
GIS	
DB manager(s)	
Geographical entities	Nb polygones
GIS size: Nb polygones	Nb entry in DB
GIS size: Nb entry in DB	
Data Entry	By field surveyor
Polygon digitization	Verification process
Metadata	
Vegetation-plot DB	
% mapped from ground survey	
% mapped from photo-interpretation	
% modelized	
% mapped from satellite images	YES/NO
Map quality assesment	
Printed maps	YES/NO
Number of maps	
Scale printed maps	
Legend	
Online GIS	YES/NO
Web site	
Levels of diffusion	

Annex 3 Descriptive fact sheets for 14 selected projects

- **Bulgaria**: Mapping and identification of conservation status of natural habitats and species
- **Czech Republic**: Biotopes map of the Czech Republic
- **Estonia, Latvia, Lithuania, Slovakia, Hungary, Slovenia, Romania and Bulgaria**: National grassland inventories
- **Finland**: Basic Data on Natural Habitat Types in Protected Areas
- **France** (Nord Pas-de-Calais region) and **United Kingdom** (County of Kent): Assessing Regional Changes to Habitats (ARCH) Project
- **Germany**: Biotope mapping
- **Greece**: Identification, description and mapping of habitat types in sites important for nature conservation in Greece (1999–2001) + Update of the description and delineation of the terrestrial habitat types in Sites of Community Importance in Greece (2013–2015)
- **Hungary**: MÉTA Programme — Database and Map of Hungarian Habitats
- **Italy**: 'Map of Nature' System
- **Norway**: Vegetation Mapping in Norway
- **Slovenia**: Vegetation map of forest communities of Slovenia
- **Spain**, Basque Country: EUNIS Habitat and Vegetation series mapping of Basque Country
- **Spain**, Catalonia: Habitat and vegetation mapping of Catalonia
- **Spain**: Mapping and inventory of Annex I habitats of Directive 92/43/EEC in Spain

BULGARIA	EU 27 ☒	EEA 32 ☒

Mapping and identification of conservation status of natural habitats and species

Territory Area	Extent of the map	Area mapped
110 879 km^2	National (Natura 2000 network)	~ 30% of the national territory
Project dates	2011 - 2013	

Project owner	Project manager
Ministry of Environment and Waters	Dicon Group Ltd.

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1:5 000	☒	Not planned

Types of objects mapped	Typology	Nb. classes typology or legend
Habitats of community interest	Ann.1 Habitat	90

Typological correspondences			
HFF	CORINE Biotopes	EUNIS	Phytosociology
☒	☐	☐	☐

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
Secondary (model validation)	Academic	~ 80

Use of satellite images	Habitat modelling
☐	☒

Online/Web GIS	Type of information system
☐	-

Project description

A project for habitat mapping within Natura 2000 sites named 'Mapping and Identification of Conservation Status of Natural Habitats and Species - Phase I' is on-going in Bulgaria. It covers all designated Bulgarian Sites of Community Importance (SCI) - about 30% of the country. The overall objective of the project is mapping and determining the conservation status of habitats and species covered by the Habitats Directive. The beneficiary of the project is the Ministry of Environment and Waters. The mapping scale is 1:5000. The list of mapping units includes 86 Annex I habitats. Due to the very limited time of the project (March 2011 – March 2013), the project activities do not envisage detailed field work, but a combination of field mapping together with validation of previously prepared models.

References and website

CZECH REPUBLIC	EU 27 ☒	EEA 32 ☒

Biotopes map of the Czech Republic

Mapování biotopů v České republice

Territory Area	Extent of the map	Area mapped
78 865 km^2	National	100 % of the national territory
Project dates	First edition of the map: 2000 – 2004 Update: 2006 – on going	

Project owner	Project manager
Nature Conservation Agency of the Czech Republic	Nature Conservation Agency of the Czech Republic

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1:10 000	☒	yes

Types of objects mapped	Typology	Nb classes typology or legend
Natural and semi-natural habitats	Czech biotopes (Chytrý et al. 2010)	177
Typological correspondences		
HFF ☒	**CORINE Biotopes** ☒	**EUNIS** ☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
majority	Contractors (+ agency staff)	First map - 770 field workers Update - 250 field workers

Use of satellite images	Habitat modelling
☐	☐

Online/Web GIS	Type of information system
☒	Centralised at national level

Project description

Habitat mapping of the Czech Republic is one of the most important habitat mapping programmes in Europe covering the entire national territory (79 000 km ^{2}) at a large scale (1:10 000). Its first objective was to help establish the Natura 2000 network in the Czech Republic. It is now widely used for different activities of the Nature Conservation Agency and its partners, examples include;- Red Book on Biotopes of the Czech Republic, Environmental Impact Assessments, policy making and university projects. The map layer and the methodology are regularly improved and updated.

References and website

Chytrý et al. (2001)., Chytrý et al., (2010). Härtel et al., (2009)

http://portal.nature.cz/publik_syst/ctihtmlpage.php?what=1035

Central and Eastern Europe

EU 27 ☒ EEA 32 ☒

National grassland inventories

Estonia, Latvia, Lithuania, Slovakia, Hungary, Slovenia, Romania, Bulgaria

Territory Area	Extent of the map(s)	Area mapped
From 64 559 km² (Latvia) to 23 8391 km² (Romania)	National	Between 0.27% (Latvia) and 16.5% (Slovakia) of the national territory
Project dates	1997 - 2006	

Project owner / Project manager
Royal Dutch Society for Nature Conservation (KNNV) in collaboration with national organisations (Fund for Nature, institutes, societies…)

Scale (Optimal use scale / Published scale)	National methodological harmonisation	Update
1:25 000	☒	not planned

Types of objects mapped	Typology	Nb classes typology or legend
Specific habitat type (natural and semi-natural grasslands)	Phytosociology (level of alliance)	19 - 39

Typological correspondences			
HFF	**Corine Biotopes**	**EUNIS**	**Phytosociology**
☒	☐(some projects)	☐	☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
secondary	various	25 - 118

Use of satellite images	Habitat modelling
☒	☐

Online/Web GIS	Type of information system
☐	GIS (2 000 - 16 000 polygons)

Project description

Grassland inventory projects were conducted in 8 Central and Eastern European countries (Estonia, Latvia, Lithuania, Slovakia, Hungary, Slovenia, Romania and Bulgaria) supported by the Dutch government in the framework of the BBI-MATRA. A standard method was proposed according to the recommendations of the European Workshop on National Grassland Inventory in Bratislava, 1999. Potential sites were selected by grassland specialists after satellite image and/or aerial photo processing. Mapping units were defined according to a phytosociological methodology. Field mapping and GIS were organised by national project co-ordinators.

The main output of the program was the preparation of a management and conservation strategies of high nature value grasslands in the frame of agri-environmental measures of the EU's Common Agricultural Policy.

References and web site

Demeter et Veen, 2001; Estonian Fund for Nature and KNNV, 2001; 2002; Kabucis et al., 2003; Kaligaric et al., 2003; Meshinev et al., 2005; Rasomavicius et al., 2006 ; Sârbu et al. 2004; Šeffer and Veen, 1999; Šeffer et al., Veen 2007

FINLAND	EU 27 ☒	EEA 32 ☒

Basic Data on Natural Habitat Types in Protected Areas

Territory Area	Extent of the map	Area mapped
338 424km^2	National (Protected Areas)	15% of the country
Project dates	2002 – 2007	

Project owner	Project manager
Metsähallitus	Metsähallitus

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
-	☒	-

Types of objects mapped	Typology	Nb. classes typology or legend
Natural and semi-natural habitat	Natural Habitat Types and Habitats of community interest	-

Typological correspondences			
HFF	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
☒	☐	☐	☐

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
Majority in Southern Finland Secondary in the Northern Finland	Agency	-

Use of satellite images	Habitat modelling
☒	☐

Online/Web GIS	Type of information system
☐	National information system (Metsähallitus' GIS)

Project description

In 2002, a 5-year nation-wide project of collecting recent data on natural habitat types in protected areas was initiated. Before this programme, there was a need for standardized data managed in a national information system and detailed information on natural habitat types. The inventory covers an area of 4.9 million hectares (15% of the territory).

The main objectives are the management of the protected areas and the monitoring of the Sites of Community Interest (Natura 2000 network). The data on natural habitat types are also used for assessing threatened habitat types in Finland.
In Southern Finland habitat mapping is collected in the field while in northern Finland inventory is mainly from remote sensing, and completed by field surveys for specific areas.

References and website

http://www.metsa.fi/sivustot/metsa/en/NaturalHeritage/SpeciesandHabitats/CollectionofDataonHabitats/Sivut/BasicDataonNaturalHabitatTypesinProtectedAreas.aspx

Kent region (U.K) Nord Pas-de-Calais region (FRANCE)	EU 27	EEA 32
	☒	☒

ARCH - Assessing Regional Changes to Habitats

Territory Area	Extent of the map	Area mapped
17 000 km² (4 000 km² Kent + 13 000km² NPDC)	Regional	100% of both regions
Project dates	2009-2012	

Project owners	Project manager
Kent County Council / Région Nord-Pas de Calais (INTERREG IV A)	Kent County Council

Scale	National Methodological harmonisation	Update
1:10 000	☐	possible

Types of objects mapped	Typology	Nb. classes typology or legend
Natural and semi-natural habitats	CORINE biotopes (adapted from level 3)	50

Typological correspondences			
HFF	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
☒	☒	☐ (partly)	☐ (partly)

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
Sample area	Contractors	Not known

Use of satellite images	Habitat modelling
☒	☐

Online/Web GIS	Type of information system
☐	-

Project description

ARCH is an ambitious project to improve knowledge and monitoring of habitats and key species in Kent (U.K.) and Nord-Pas de Calais (France) regions in the frame of the Interreg IVA-Two Seas cooperation programme.

A regional and cross-border vectorial and georeferenced database of natural habitats to a 1:10 000 scale was produced and a chronological analysis of the evolution of natural habitats of both cross-border territories. Mapping is made from interpretation of aerial photography completed with field survey. A common classification has been defined based on CORINE Biotopes.

One of the results was the development of an online mapping tool in Nord-Pas de Calais and of a planning and a screening software solution in Kent available to planners and environment professionals.

Finally, the feasibility of developing and implementing a long-term system to monitor changes in extent, quality and fragmentation of habitat across the project area was investigated.

References and website

http://www.archnature.eu/

http://www.nordpasdecalais.fr/upload/depotWeb/arch_natural_habitats.html

Germany	EU 27 ☒	EEA 32 ☒

Biotope mapping

Biotopkartierung

Territory Area	Extent of the map	Area mapped
357 000 km^2	Regional	(not known)
Project dates	1970s' – on-going	

Project owners	Project manager
The 16 German Federal States (*Bundesländer*)	Varies

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1:5 000 – 1:25 000	☐	yes
Types of objects mapped	**Typology**	**Nb classes typology or legend**
Natural and semi-natural habitats (mainly protected habitats)	Regional lists of biotopes	-

Typological correspondences			
N2000	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
☒	depending	depending	partly

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
majority	Contractors / agency staff	-

Use of satellite images	Habitat modelling
☒☐ (depending)	☒☐ (depending)

Web GIS	Type of information system
depending	Regional

Project description

In the 1970s with increased awareness of whole ecosystems and biotopes being under threat and increasing pressures biotope mapping projects were launched in most of the German Federal States (*Bundesländer*). Biotope-mapping definitions and programmes were developed independently in the 16 German Federal States, and in most cases a selective mapping of only those biotopes considered to be threatened was carried out. In some cases this was restricted to protected areas only. Most of the German Federal States have refined and adapted their methods and now have data of three full successive mapping periods. The actual situation and availability of data is summarised in Kaiser et al., (2013). In 1993 a first German Standard-list of biotopes (Blab und Riecken, 1993) was published, in 1994 a first edition of a Red Data Book of German Biotope Types appeared (Riecken et al., 1994). Currently the second edition (Riecken et al., 2006) is available and a third edition is scheduled for 2016.

References and website

Bayerisches Landesamt für Umweltschutz, 2004; Conze, K.-J., 2007; Kaiser et al., 2013; LUNG, 2010; Riecken et al., 2006; Von Drachenfelds, O., 2011.;

GREECE	EU 27 ☒	EEA 32 ☒

Identification, description and mapping of habitat types in Sites of Community Importance for Nature Conservation of Greece (1999-2001) Update of the description and delineation of the terrestrial habitat types in Sites of Community Importance in Greece (2013-2015)

Territory Area	Extent of the map	Area mapped
131 957 km^2	Natura 2000 network – Sites of Community Importance	15% of the national territory (2.000.000 ha)
Project dates	Project 1: 1999 - 2001 Project 2: 2013 - 2015	

Project owner	Project manager
Ministry of Environment, Regional Planning and Public Works Ministry of Environment, Energy and Climate Change	Project 1: Private companies & Universities (Athens, Patras, Thessaloniki) with scientific coordinators Project 2: Private companies & Universities (Ioannina, Thessaloniki) with scientific coordinators

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
(Project 1) / 1: 20 000 (Project 1) / 1: 5 000	☒ ☒	☒

Types of objects mapped	Typology	Nb. classes typology or legend
Natural and semi-natural habitats	Phytosociology + Annex 1 Habitat types + Hellenic habitat types	-

Typological correspondences			
HFF	CORINE Biotopes	EUNIS	Phytosociology
☒	☒	☐	☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
majority	University	More than 80

Use of satellite images	Habitat modelling
Project 1: ☒ (use of b/w aerial photos) Project 2: ☒ (use of colour ortho-photos)	☐

Online/Web GIS	Type of information system
☐	National (centralised)

Project description

With 27% of its territory included in the Natura 2000 network, Greece has one of the highest proportions of Sites of Community Importance (SCI) and Special Protection Areas (SPAs) in Europe. Two important projects were carried out in order to identify, describe and map all Annex I habitat types in 237 (1999-2001) and 242 (2013-2015) terrestrial SCIs (ca. 20 000 km^2). The first project (1999-2001) was mainly designed for inventory purposes including detailed characterisation and mapping of the vegetation communities and the corresponding Annex I habitat types included in the designated SCIs. The second project (2013-2015) will use similar methodology to update the description and to map more accurately the habitat types of the SCIs, but with a monitoring objective in combination to the assessment of their conservation status.

References and website

Dimopoulos *et al.*, 2005, 2006, Dimopoulos (2013) – pers. comm.

HUNGARY	EU 27 ☒	EEA 32 ☒

MÉTA Programme - Database and Map of Hungarian Habitats

MÉTA Program - Magyarország Élőhelyeinek Térképi Adatbázisa

Territory Area	Extent of the map	Area mapped
93 028 km^2	National	> 90% of the national territory
Project dates	2003 - 2006	

Project owner	Project manager
MTA ÖBKI	MTA ÖBKI

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
~ 1: 200 000 (Hexagonal grid: cell size = 35 ha)	☒	☐

Types of objects mapped	Typology	Nb. classes typology or legend
All habitats	Á-NÉR classification	86
Typological correspondences		
HFF ☒	**CORINE Biotopes** ☒	**EUNIS** ☒

Actual vegetation	Potential vegetation
☒	☒

Field work	Type of operator	Human resources (surveyors)
Majority	-	300

Use of satellite images	Habitat modelling
☒	☐

Online/Web GIS	Type of information system
☒	National (centralised)

Project description

MÉTA is the one of most important nation-wide habitat mapping programme in Europe. It is defined as a grid-based, landscape-ecology-oriented, satellite-image supported, field vegetation mapping method. The objective of the map is to evaluate Hungarian (semi-) natural habitats and landscapes through vegetation surveys. Data collected is also used for the prognosis of future changes of vegetation and landscapes.

The methodology was designed to obtain the most homogeneous results possible. The survey is based on hexagonal grids with cells of 35 hectares. A national habitat classification was specifically developed for field mapping purposes with the objective to be suitable for use by a large number of surveyors (around 300).

References and website

Molnár et al., 2007; Bölöni et al., 2008; Horváth et Polgár, 2008; Horváth et al., 2008

http://www.novenyzetiterkep.hu/magyar/katalogus/node/73

ITALY	EU 27 ☒	EEA 32 ☒

“Map of Nature” System
Sistema “Carta della Natura”

Territory Area	Extent of the map	Area mapped
301 336 km^2	National	Scale 1:10 000: ± 0,003% of the national territory Scale 1:50 000: ± 46,4% of the national territory Scale 1:250 000: 100% of the national territory
Project dates	Scale 1:10 000: 2009 - on going Scale 1:50 000: 2005 - on going Scale 1:250 000: 1991 - 2003	

Project owner	Project manager
Ministero dell’Ambiente e della tutela del territorio e del Mare	ISPRA

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
Multi-scalar approach: 1:10 000, 1:50 000 and 1:250 000	☒	☒

Types of objects mapped	Typology	Nb. classes typology or legend
All habitats	Scale 1:10 000 and 50 000: CORINE Biotopes (now being converted to EUNIS) Scale 1:250 000: landscape units	Scale 1:10 000 and 50 000: 230 Scale 1:250 000: 37
Typological correspondences		
HFF ☒	**CORINE Biotopes** ☒	**EUNIS** ☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
Scale 1:10 000 and 50 000: majority Scale 1:250 000: secondary	Contractors and universities	> 50

Use of satellite images	Habitat modelling
☒	☒

Online/Web GIS	Type of information system
☒	Central, with regional allocation of data

Project description

The *Carta della Natura* System was developed In order to fulfil the Italian framework law on protected areas with the objective to identify the status of the natural environment and assess its quality and fragility.

It is developed at 3 different scales (1:10 000, 1:50 000 and 1:250 000) and organised in two main phases: mapping environmentally homogeneous territorial units, and developing models and procedures that allow the production of thematic maps and quality indicators.

References and website

Amadei et al., 2003, 2004; Angelini et al., 2009a; b; Augello et Bianco, 2008; Bagnaia et al., 2009; Feoli, 2008

http://sgi2.isprambiente.it/SistemaCartaNatura/

NORWAY	EU 27 ☐	EEA 32 ☒

Vegetation Mapping in Norway

Vegetasjonskartlegging i Norge

Territory Area	Extent of the map	Area mapped
386 204 km²	National	9.35% % of the national territory (30 305 km²)
Project dates	1979- on-going	

Project owner	Project manager
Norwegian Forest and Landscape Institute (NIJOS)	Norwegian Forest and Landscape Institute

Scale	National Methodological harmonisation	Update
1:25 000	☒	-

Types of objects mapped	Typology	Nb. classes typology or legend
Natural and semi-natural habitats	Rekdal, Y. & Larsson, J.Y.(2005)	54

Typological correspondences			
HFF	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
☐	☐	☐	☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
majority	Agency staff	7

Use of satellite images	Habitat modelling
☐	☐

Online/Web GIS	Type of information system
☒	-

Project description

In Norway in the last 30 years most of the habitat mapping activity has been undertaken by the Norwegian Forest and Landscape Institute (NIJOS). An operational field mapping system developed in the 1980s and improved in 2005. It contains 54 vegetation types mainly based on physiognomy, i.e. dominant species or species groups, secondly by characteristic species. It is designed to be used at scales between 1:20 000 and 1:50 000. Every year around 500 km² are mapped using this mapping system.

The other nationwide vegetation classification available for Norway, Fremstad (1997), is more detailed and adapted for mapping at scales between 1:5 000 and 1:20 000. However since it is more time-consuming (productivity was estimated at 0.5–1 km² per day) it has not been used to cover wide areas. Units from this detailed system can be aggregated to units in the survey map system.

References and website

Rekdal, Y. & Larsson, J.Y. 2005, Rekdal and Bryn 2003, Fremstad 1997

http://kilden.skogoglandskap.no/map/kilden/index.jsp

SLOVENIA	EU 27 ☒	EEA 32 ☒

Vegetation map of forest communities of Slovenia

Vegetacijska karta gozdnih združb

Territory Area	Extent of the map	Area mapped
20 273 km^2	National	57% of the country
Project dates	1962 - 2008	

Project owner	Project manager
Biološki inštitut Jovana Hadžija (ZRC SAZU)	Biološki inštitut Jovana Hadžija (ZRC SAZU)

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1:50 000 / 1:400 000	☒	Not planned

Types of objects mapped	Typology	Nb. classes typology or legend	
Forest communities	Phytosociology (level of association)	61	
Typological correspondences			
HFF	CORINE Biotopes	EUNIS	Phytosociology
☒	☒	☐ possible	☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
No fieldwork (synthesis of existing maps and vegetation plots)	Institute staff	-

Use of satellite images	Habitat modelling
☐	☐

Online/Web GIS	Type of information system
☒	National (ZRC SAZU)

Project description

Slovenian forests cover more than half of the territory and have been well studied over the last century. This publication is a synthesis of the vegetation map of Yugoslavia project initiated in the 1960s and other forest vegetation surveys. Vegetation plots (relevés) were used to define plant associations as basic mapping units. Associations are defined according to characteristic and differential species and they represent a well recognizable response to abiotic and biotic factors. The vegetation map by scientific research center SAZU is a generalization of these units on homogenous surfaces. It is published as an interactive map at a scale of 1:400 000 but most of the sheets are available at a 1:50 000.

References and website

Marinček et al. 2002

http://www.metsa.fi/sivustot/metsa/en/NaturalHeritage/SpeciesandHabitats/CollectionofDataonHabitats/Sivut/BasicDataonNaturalHabitatTypesinProtectedAreas.aspx

Basque Country (SPAIN)	EU 27 ☒	EEA 32 ☒

EUNIS Habitat and Vegetation series mapping of Basque Country

Cartografía de Vegetación y usos del suelo de la CAPV (MV2005)
Mapa de series vegetación de la CAPV

Territory Area	Extent of the map	Area mapped
7 235 km^2	Regional	100 % of the regional territory
Project dates	MV2005 : 2004 - 2006 Vegetation series : 2004 - 2006	

Project owner	Project manager
MV2005 : CAPV Vegetation series : CAPV	MV2005 : IKT Vegetation series : UPV/EHU

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
MV2005 : 1:10 000 Vegetation series : 1:50 000	MV2005 : ☐ Vegetation series : ☐	MV2005 : yes (2007) Vegetation series : not planned

Types of objects mapped	Typology	Nb classes typology or legend
MV2005 : All habitats + land use Vegetation series : Natural and semi-natural habitats	MV2005 : EUNIS Vegetation series : Phytosociology	MV2005 : 235 Vegetation series : 24

Typological correspondences			
HFF	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
MV2005 : ☒ Vegetation series : ☐	MV2005 : ☐ Vegetation series : ☐	MV2005 : ☒ Vegetation series : ☐	MV2005 : ☒ (partly) Vegetation series : ☒

Actual vegetation	Potential vegetation
MV2005 : ☒ Vegetation series : ☐	MV2005 : ☐ Vegetation series : ☒

Field work	Type of operator	Human resources (surveyors)
MV2005 : majority Vegetation series : majority	EUNIS : contractors Vegetation series : universities	EUNIS : >20 Vegetation series :5

Use of satellite images	Habitat modelling
MV2005 : ☐ Vegetation series : ☐	MV2005 : ☐ Vegetation series : ☐

Web GIS	Type of information system
MV2005 : ☒ Vegetation series : ☐	MV2005 : regional (CAPV) Vegetation series : Universidad del País Vasco

Project description

The Vegetation and land use mapping of the Basque country (MV2005) started in the early 1990s at a scale of 1:25 000 with a specific typology. A first update was made in 2005 at a scale of 1:10 000 and the typology changed to EUNIS. The last revision was published in 2010.

The vegetation series mapping of the Basque Country at a scale 1:50 000 is based on very detailed knowledge of the plant communities, the legend accompanying the map is a detailed description of the plant landscapes and their dynamics.

References and website

Loidi et. al. (2011), IKT. (2010).

Catalonia (SPAIN)	EU 27 ☒	EEA 32 ☒

Habitat and vegetation mapping of Catalonia

Cartografia dels hàbitats de Catalunya (CHC50)+Mapa de vegetació de Catalunya(VMC50)

Territory Area	Extent of the map	Area mapped
32 113 km^2	Regional	CHC 50: 100 % of the regional territory Vegetation map: ≈ 80 %
Project dates	CHC 50: 1998 - 2003 Vegetation map : 1983 – on going	

Project owner	Project manager
Departament de Medi Ambient i Habitatge de la Generalitat de Catalunya	Universitat de Barcelona (Grup de Recerca de Geobotànica i Cartografia de la Vegetació)

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1:50 000	CHC 50: ☐ VMC 50 : ☐	CHC 50: yes VMC 50 : not planned

Types of objects mapped	Typology	Nb classes typology or legend
Natural and semi-natural habitats	CHC 50: CORINE Biotopes VMC 50 : Phytosociology	CHC 50: 109 VMC 50 : not know

Typological correspondences			
HFF	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
CHC 50: ☒ VMC 50 : ☐	CHC 50: ☒ VMC 50 : ☐	CHC 50: ☐ VMC 50 : ☐	CHC 50: ☐ partly VMC 50 : ☒

Actual vegetation	Potential vegetation
CHC 50: ☒ VMC 50 : ☒	CHC 50: ☐ VMC 50 : ☒

Field work	Type of operator	Human resources (surveyors)
CHC 50: ☒ VMC 50 : ☒	CHC 50: universities VMC 50 : universities	CHC 50: 180 VMC 50 : 40

Use of satellite images	Habitat modelling
CHC 50: ☐ VMC 50 : ☐	CHC 50: ☐ VMC 50 : ☐

Web GIS	Type of information system
CHC 50: ☒ VMC 50 : ☒	Common regional information system (CHC 50 + VMC 50)

Project description

In 1983 a research team of the University of Barcelona started the Vegetation Map of Catalonia project (VMC50) with the objective to produce 89 sheets at a scale of 1:50 000 covering the 32 000 km² of the region. This project was a heritage of an important work in floristic and phytosociology in Catalonia in the second half of last century. One of its main advantages is the representation of both actual and potential stages of vegetation on the same map. In the 1990s the creation of the Natura 2000 network required additional environmental information on habitats and the Catalan Government (*Generalitat de Catalunya*) funded the Map of Catalan habitats project (CHC50) based on the European CORINE Biotopes typology. Both projects (VMC50 and CHC50) are based on similar methodologies and have been recently merged into a single GIS. Nowadays this product is also widely used as a tool in land management.

References and website

Carreras, 1997; Vigo *et al.*, 2005, 2006; Carreras *et al.*, 2006

http://www.ub.edu/geoveg/en/mapes.php

SPAIN	EU 27 ☒	EEA 32 ☒

Mapping and inventory of Annex I habitats of the Directive 92/43/EEC in Spain

Cartografía e inventariación de los tipos de hábitats de la Directiva 92/43/CEE en España

Territory Area	Extent of the map	Area mapped
505 989 km^2	National	≈24% of the national territory
Project dates	1993 - 1996	

Project owner	Project manager
Ministerio de Agricultura, Alimentación y Medio Ambiente (MAAME)	Task Force of the MAAME

Scale (Optimal use scale / Published scale)	National Methodological harmonisation	Update
1: 50 000	☒	-

Types of objects mapped	Typology	Nb. classes typology or legend
Habitats of Community Interest	Ann. 1 Habitats + Phytosociology (level of association)	1700 sub-types

Typological correspondences			
N2000	**CORINE Biotopes**	**EUNIS**	**Phytosociology**
☒	☒	☐	☒

Actual vegetation	Potential vegetation
☒	☐

Field work	Type of operator	Human resources (surveyors)
Majority	Contractors and universities	250

Use of satellite images	Habitat modelling
☐	☐

Web GIS	Type of information system
☐	National

Project description

Spain was the first country in Europe to conduct a national survey of Annex I habitats in order to identify potential Natura 2000 sites. This ambitious project led by ICONA (Spanish Institute for Nature Conservation) and financially supported by EU Life funds involved around 30 institutes and research centres across the country.

Prior to the field work a Spanish interpretation manual for the Annex I habitats was prepared by Prof. S. Rivas-Martínez. The manual describes the Annex I habitats found in Spain, their correspondence with phytosociological classifications and the units to be mapped. Between 1994 and 1996, 1 114 sheets at a scale of 1:50 000 were produced. The sheets were digitized after the end of the project, thus limiting its application at large scales due to topological inconstancies.

References and website

Loidi Arregui, 1999; Rivas-Martínez *et al.*, 1993

Annex 4 Synthesis of more commonly used approaches for mapping and modelling species and habitats distributions

Concept	Technique	Model	Specific software application	Observation data types	Key references
Maximum entropy	Information theory	Maxent	Maxent	P	Phillips et al., 2006
Habitat suitability mapping	Distance to average Model Frequency of occurrence Ecological GIS-toolkit	Ecological Niche Factor Analysis (ENFA)	BIOMAPPER	P	Hirzel et al., 2002
	Multivariate analysis: Ordination as exploratory method (e.g. PCA, CA, DCA, CCA, RDA)	/	Non (but: *R* ([a]); CANOCO ([b]))	P/A	Ter Braak, 1986, 1987
Environmental envelope	Neural nets	SPECIES	Stuttgart Neural Network Simulator (SNNS)	P/A	Pearson et al., 2002
	Classification and regression TREE (CART)	BIOCLIM (+ adaptations: HABITAT; SRE)	BIOCLIM	P, P/A	Busby 1991, Nix 1986; Walker & Cocks, 1991
	Similarity indices	DOMAIN	Domain	P, P/A	Carpenter et al., 1993
	Mahalanobis distance	Scale invariant correlations	Non (but: ArcView, MATLAB)	P	Farber & Kadmon, 2003; Shao & Halpin, 1995
Regression analysis	Linear models/ additives models/least square fitting Combination of regression decision Trees & 'boosting' *	GLMs/GAMs & adaptations: Multivariate adaptive regression splines (MARS)	Non (but: R ([a]))	P/A	ex: Guisan et al., 2002, Pearce & Ferrier, 2000; Friedman 1991
Genetic algorithm	*Genetic algorithm*	GARP (Genetic Algorithm for Rule-set Production)	GARP Modelling System/Desktop GARP	P/A P, P/A, Ab	ex: Guisan et al., 2002, Pearce & Ferrier, 2000; Friedman 1991 Stockwell & Noble, 1991
Bayes Theorem	Bayesian statistics	/	Non (but: ArcView, WofE)	P/classes	Bonham-Carter et al., 1989; Aspinall, 1992

Concept	Technique	Model	Specific software application	Observation data types	Key references
Geostatistics Techniques de classifications (decision rules)	Kriging interpolation	/	Non (but: MATLAB DACE toolbox; ArcGIS Geostats, *R* ([a]))	P, P/A	Kriging interpolation

Note: * boosting = method combining several simple models to improve predictions performance.

([a]) = *R* development core team (2012)

([b]) = (Document_not_found, n.d.)

Software: examples in parentheses correspond to generic types of existing software.

Data types: P = presence, P/A = presence/absence, Ab = abundance.

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