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THE IMPACTS OF CLIMATE CHANGE ON PLANT SPECIES IN EUROPE

FINAL VERSION

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EXECUTIVE SUMMARY

A summary is given of the current state of conservation of plant diversity in Europe and gaps in our baseline knowlege are identified. Published data on the recent effects on climate change on European plants are reviewed, including changes in phenology and altitudinal shifts. All the available evidence points to the high probability that plant diversity, both at the landscape and ecosystem level and at the species and population level will be severely impacted by climate change over the course of this century, interacting with other forms of global change such as population growth and movement and changes in disturbance regimes. The impacts will not be uniform, with some regions such as northern Europe experiencing moderate changes and turnover of species, while others, especially in the Mediterranean region and high mountain ranges may expect serious disruption of existing ecosystems and their replacement with novel assemblages of species and the loss of considerable numbers of currently rare and endangered species in specialized habitats. Many species that are not currently threatened or on national Red Lists may be put at risk by climate change, while others will be at risk of extinction through lack of suitable niches into which to migrate. While we have developed increasingly sophisticated tools and modelling procedures, very considerable uncertainty remains about species migrations and habitat change at the local scale. The advantages and disadvantages of bioclimatic modelling are reviewed. It is very likely that there will be a substantial rise in the number of invasive species as a result of climate and other factors of global change, with serious effects on particular habitats.

While recognizing that the Bern Convention, the Habitats Directive and individual countries have made major progress in determining which species required priority action through habitat conservation and the creation of ecological networks, implementation is not yet complete, especially in terms of area management and species-level conservation.

Given that baseline data are still far from complete, for example on threatened species, identity and extent of invasions, the number of species for which conservation/management/recovery plans have been implemented, it is difficult to determine appropriate targets for action.

The various conservation strategies available, both *in situ* and *ex situ* are considered and the need for a critical look at their effectiveness is stressed, as well as detailed consideration of novel approaches such as *inter situs* conservation, human assisted migration and conservation outside protected areas. .

An Annex is provided containing all Bern Convention listed species and information on their conservation status, availability of recovery plans and georeferenced points for niche modelling.

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1. THE CONTEXT AND RECENT DEVELOPMENTS

'Even the most restrictive emissions policies proposed to date leave a sizeable chance that significant climate change will occur over the next several decades, probably surpassing the 2 °C warming target adopted by the European Union and held by many as a dangerous limit beyond which we should not pass', Parry & al. (2009).

1.1 Introduction

The impacts of climate change on European plant life are of major concern to humankind because plants, apart from their intrinsic interest, play a vital role in ecosystem function and in food production and security. They also have a significance for other groups of organisms which depend on plants for habitat. Unlike some other groups of organisms, plants are sessile and only able to move through dispersal of pollen, seeds and other propagules, which slows migration, and this makes them less able to respond to climate change. Similarly, vegetation is essentially static and a fixed system of terrestrial protected areas is vulnerable to rapid environmental change.

It is fairly certain that the effects of changing temperature and precipitation regimes will interact with other drivers to affect a range of biological processes and the distribution of ecosystems and species. The *European Environment Outlook* (EEA 2005) notes that 'Significant changes in the distribution of plant species in Europe are expected during this century, particularly in the south-east. Most European Member States are expected to lose more than 50 species by 2100 compared with the 1995 situation. The Scandinavian and Baltic countries are expected to gain significant numbers of new species, probably as a result of higher temperatures and precipitation resulting from climate change'.

Other contributions in this series (Araújo 2009; Berry 2008; Huntley 2007) have summarized much of the evidence, including that reported in the latest reports of the Intergovernmental Panel on Climate Change (IPCC 2007 a,b) and in particular vulnerability in Europe, and so will not be repeated here. They have also covered many of the issues of responses to climate change, migration, adaptation strategies, the role of protected areas, bioclimatic modelling and its limitations, conservation needs and so on and where appropriate I have made cross reference to their reports. A vast amount of research on biodiversity and global change in Europe is reported in the Minimisation of and Adaptation to Climate Change impacts on Biodiversity (MACIS)[1] project evidence (for a summary see Kühn *et al.* 2008) and in the EEA/JRC/WHO (2008) review of impacts of Europe's changing climate. The Draft Findings of the CBD Ad Hoc Technical Expert Group on Biodiversity and Climate Change[2] only became available after this report was drafted. A global review of plants and climate change was published by BGCI (Hawkins et al. 2008). This present report will focus more on the present state of plant diversity in Europe, its state of conservation, the evidence for recent impacts of climate change, the predicted impacts and will make a series of recommendations on the wide range of actions that could be taken to mitigate these effects.

As is true for other groups of organisms, our ability to predict the responses of plant life to climate change depends to a large extent on the extent and detail of that change. It should be noted, however, that recent evidence only serves to stress the level of uncertainty of the current climate models that provide the basis for IPCC projections of future climate change. For example, although not authoritative, the first key message, on climatic trends, to come out of the 2009 International Scientific Congress on Climate Change, Copenhagen, was:

> 'Recent observations confirm that, given high rates of observed emissions, the worst-case IPCC scenario trajectories (or even worse) are being realised. For many key parameters, the climate system is already moving beyond the patterns of natural variability within which our society and economy have developed and thrived. These parameters include global mean surface temperature, sea-level rise, ocean and ice sheet dynamics, ocean acidification, and

[1] http://www.macis-project.net/pub.html
[2] http://www.cbd.int/climate/meetings/ahteg-bdcc-02-02/ahteg-bdcc-02-02-findings-review-en.pdf

extreme climatic events. There is a significant risk that many of the trends will accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts'.

Many of the model-based predictions concerning the ways in which plants will react to climate changes have been based on less pessimistic trajectories. This introduces a considerable level of uncertainty which will persist until more advanced and robust modelling is available to the IPCC. Other major areas of uncertainty are the possible climatic consequences of changes in the location of the jet stream and the alternative scenarios for W. Europe if the Thermohaline pump slows down considerably or closes down altogether.

Of considerable concern is the fact that it is becoming increasingly unlikely that we will be able to meet the European Union's Millennium goals . In its mid-term assessment of implementing the EC Biodiversity Action Plan[3], it is noted that although there is some progress in delivery, 'it is highly unlikely - on the basis of current efforts - that the overall goal of halting biodiversity loss in the EU by 2010 will be achieved. This will require significant additional commitment by the European Community and the EU Member States over the next two years, if we are even to come close to our objective'. Indeed it is now accepted that the EU 2010 target will not be met (Schutyser & Conde 2009) and the focus is now moving to the post-2100 situation and possible targets. Less than half of the protected species and habitats in Europe are considered to be in 'favourable conservation status'. For most of the remaining species and habitats, the conservation status is considered to be either inadequate or bad. Furthermore, for a significant number of species and habitats, the data at hand are simply insufficient to reach any assessment (EEA 2008).

A study on 'The economics of ecosystems and biodiversity' (TEEB)[4] concludes that, in a 'businessas usual' scenario, the current decline in biodiversity and related loss of ecosystem services willcontinue and even accelerate. By 2050 we will be faced with an estimated further loss of 11% of the natural areas that still existed in 2000. Almost 40% of the land currently under low-impact forms of agriculture could be converted to intensive agricultural use.

1.2 Global change

It is important to stress that plants like other organisms and their habitats will be affected not just by climate change but by the other factors that make up global change (Box 1.1). While much of the focus in recent years has been on the impacts of climate change, these do not operate, now nor will in the future, in isolation but closely interact with human population changes and alterations in disturbance regimes. The growth in the human population and the expansion of the global economy over the coming decades will lead to an increase in the demand for land for food production and energy crops and adversely impact on wild biodiversity and on protected areas. As well as demographic growth, Europe has seen considerable population movements in the past century such as movement away from the land to the cities. In the Mediterranean region, terracing, a traditional form of land use, has been largely abandoned with considerable landscape impacts. Another form of population migration, albeit temporary, is annual tourism which in some areas of Europe has led to massive urban and tourist development with accompanying infrastructural effects. This is especially accentuated in coastal areas of the Mediterranean and on islands, leading to the phenomenon known as 'coastalization'. This has inevitably led to an impoverishment of biodiversity, loss or fragmentation of habitats and is projected to increase.

Climate change and land-use change are both key drivers of biodiversity change and when their effects are examined separately, we are likely to underestimate the extent of projected changes on biodiversity (Chazal & Rounsevell 2009). This is particularly relevant when considering the future migrations of plants through bioclimatic modelling (Section 5) and the nature and state of the 'new' habitats that develop.

[3] http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/bap_2008_en.pdf
[4] http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/teeb_report.pdf

Box 1.1 The main components of global change

Population change

- Human population movement/migrations
- Demographic growth
- Changes in population pattern

Changes in land use and disturbance regimes

Climate change (IPPC definition)

- Temperature change
- Atmospheric change (greenhouse gases: carbon dioxide, methane, ozone, and nitrous oxide)

Other climate-related factors

- Distribution of Nitrogen deposition
- Air pollution in mega-cities

2. SUMMARY OF EVIDENCE OF THE RECENT EFFECTS OF CLIMATE CHANGE ON EUROPEAN PLANTS

Substantial evidence is accumulating that documents changes in phenology, species-interactions and changing distributions attributed to the effects of climate change on European plants during the past 50 or so years from several countries. Unfortunately, as Berry (2008) has already pointed out, there is little information available on the sensitivity and vulnerability of Bern Convention Appendix 1 species in particular. On the other hand, many of these species are known to be rare and/or endangered, with limited or fragmented distributions, and often grow in specialized habitats in mountain or alpine zones, often on islands which are subject to additional stresses, habitats which are known to be especially vulnerable to climate change. Thus, there is sometimes information on the reactions of comparable species from such habitats and this clearly indicates the risks to which such species are exposed.

2.1 Phenology

Some of the commonest reported ways in which species have responded to climate change are changes in time of budburst, flowering, fruiting, leaf coloration and leaf-fall. For a summary of the growing body of evidence for European plants see Table 2.1 and for a review see Cleland *et al.* (2007). The date of first flowering is sensitive to temperature so that predicted rises of 2-5 C will be expected to have major impacts. Miller-Rushing *et al.* (2008) caution against assuming that changes in the first flowering date describe the phenological behaviour of whole populations and recommend that researchers consider the effects of changes in population size and sampling frequency when interpreting changes in flowering dates. In the short term, these changes are simply expressions of plasticity among the genotypes in the population. In the long term, these changes will alter the balance of reproductive success among competing genotypes, i.e. adaptation to change. We need therefore to distinguish between evolutionary change and temporary (and reversible) reaction to climatic change.

Other factors than temperature affect phenology as well. For example, Peñuelas & al. (2004) showed that changes in rainfall and water availability, an important driver of climate change, can cause complex phenological changes with likely far-reaching consequences for ecosystem and biosphere functioning and structure. Prieto *et al.* (2008) showed that autumn flowering of *Globularia alypum* and *Erica multiflora* are more dependent on water availability than temperature and that extreme changes in rainfall patterns in spring and summer could seriously affect the flowering time of the former while the latter was more resilient.

Europe is fortunate in having a long-standing tradition in collecting phenological data with long-term data sets available in several countries (Menzel 2003). Phenological networks have been established since the middle of the 18th century and data are available for many European countries (e.g. Ahas et al. 2002; Chmielewski et al. 2004; Chmielewski & Rötzer 2002; Defila & Clot 2001; Schaber & Badeck 2005). A phenological network was created in Spain by the Instituto Nacional de Meteoreología in 1942 and an analysis of c. 204 000 records gathered and digitized from the INM archives for the period 1943–2003 for 29 perennial plant species was made by Gordo & Sanz (2009). Claimed to be the longest temporal and broadest spatial assessment of plant phenological changes in the Medditerranean region it revealed that the great majority of species showed a shift in leraf unfolding, flowering and fruiting in recent decades. A recent network is the International Phenological Gardens (IPG) founded in 1957 and now baed at the Institute of Crop Sciences at Humboldt University in Berlin (Chmielewski, 1996; Menzel & Fabian, 1999; Menzel, 2000; Chmielewski & Rotzer, 2001). The basic goal of the IPG is to obtain comparable phenological data for plants across Europe by studying cloned material of trees and shrubs at various botanic gardens and other locations, the idea of using cloned material being to avoid the influences of genetic variation on the phenological observations. The IPG database now contains *c*. 65 000 observations on 23 plant species at *c*. 50 botanic gardens across Europe (Menzel, 2003). The species involved were: *Larix decidua, Picea abies, P. omorika, Pinus sylvestris, Betula pubescens, B. pendula, Fagus sylvatica. , F. orientalis, Populus canescens, P. tremula, Prunus avium, Quercus petraea, Q. robur, Robinia pseudoacacia, Sorbus aucuparia, Tilia cordata, Ribes alpinum, Salix aurita, S. acutifolia, S. smithiana, S. glauca, S. ×viminalis, Sambucus nigra, Corylus avellana, Forsythia suspensa 'Fortunei', Syringa × chinensis.*

An analysis of observational data from the IPG for the period 1959-1996 showed that spring events, such as leaf unfolding, have advanced on average by 6.3 days (-0.21 day/year), whereas autumn events, such as leaf colouring, have been delayed on average by 4.5 days (+0.15 day/year). Consequently, the average annual growing season has lengthened on average by 10.8 days since the early 1960s. For autumn events, differences between mean trends of species could not be detected, but for spring events there were differences between species, with the higher trends for leaf unfolding and flowering of shrubs indicating that changes in events occurring in the early spring are more distinct (Menzel 2000; Menzel & Fabian 1999). They also noted that shrubs seem to be more responsive to changes in temperature than are trees (Menzel, 2000) and as might be expected, there are regional differences with more marked phenological changes in the spring of northern Europe compared with southern Europe.

Table 2.1. Phenology changes in plants reported in the literature (partly based on Olofsson & al. 2008).

Study	Area	Period	Phenology change
Ahas 1999	Estonia	1916–1996	earlier spring (1.0 day/decade)
Menzel & Fabian (1999)	Europe	1959–1993	earlier spring (1.8 days/decade) delayed autumn (1.4 days/decade)
Menzel & al. (2006)	Europe (21 countries)	1971–2000	earlier spring/summer (2.5 days/decade)
Fitter & Fitter (2002)	UK	1954–2000	first flowering (4.5 days/decade in the 1990s)
Peñuelas (2002)	Spain	1952–2000	earlier leafing (3 days/ decade) earlier flowering (1.2 days/decade) earlier fruiting (3.5 days/decade) delayed leaf-fall (2.7 days/decade)
Schaber & Badeck (2005)	Germany	1880–1999	earlier flowering (up to 21 days/ decade), earlier budburst (up to 8 days/decade), longer vegetative period (up to 7.3 days/decade) (all values for 1984–89)

The IPG have been incorporated into a study undertaken by Menzel & al.(2006) which is claimed to be the world's largest phenology survey, involving collaboration between scientists from 17 countries. More than 125 000 observational series of 542 plant and 19 animal species in 21 European countries were examined over the period 1971–2000 and clear evidence is given that climate change is affecting the seasons.. The results showed that spring arrives an average of 6-8 days earlier that it did in the past. And in countries where rapid increases in temperature have occurred, that figure is almost doubled. They concluded that the average advance of spring/summer was 2.5 days decade^{-1} in Europe and their analysis of 254 mean national time series clearly indicated that the phenology of species is responsive to the temperature of the preceding months (mean advance of spring/summer by 2.5 days°C^{-1}, delay of leaf colouring and fall by 1.0 day°C^{-1}). The pattern of observed change in spring efficiently matches measured national warming across 19 European countries (correlation coefficient **r**=−0.69, P<0.001)'.

Botanic gardens in particular have been engaged in the study of plant-climate interactions, in the case of the Royal Botanic Garden Edinburgh since the middle of the 18th century (Harper *et al.* 2004; Harper & Morris 2006; Harper & Morris 2007)), and the role of botanic gardens in maintaining data sets on phenology of a wide diversity of plants is reviewed by Primack and Miller-Rushing (2009).

2.2 Altitudinal shifts

There is already considerable evidence of the upwards altitudinal migration of plants in various parts of Europe, attributed to climate change. As Bresheras & al (2008) note 'Warming temperatures associated with anthropogenic increases in greenhouse gases have led ecologists to predict that vegetation gradients will ''march'' up the hill as climate envelopes shift with elevation, at a lag that scales with species' generation times...' As they point out the significance of such a response has important implications for predicting and mitigating the impacts of climate change impacts, particularly for vegetation that occurs over a range of altitudinal gradients. If, the responses of the dominant species that occur along gradients are highly individualistic, rather than them collectively moving with climate change, the greater is the likelihood of novel, non-analogue vegetation assemblages resulting. Such novel assemblages or emerging ecosystems may pose management challenges (Hobbs & al. 2006; Lindenmayer & al. 2008).

Kelly and Goulden (2008) document how dominant plant species along an entire, contiguous valley–mountain gradient spanning more than 2,000 m in elevation along the Santa Rosa Mountains in southern California shifted their distributions upslope synchronously with one another in response to anthropogenic warming of the regional climate. This contrasts with what would have been expected in the light of current understanding and evidence from palaeoecology that vegetation responses lag behind climate changes. However, in this study, the range limits of each dominant species, remained unchanged. Consequently, in contrast to expectations of a ''march'' up the hill, the vegetation gradient essentially synchronously 'leaned' upslope—the distribution shifted upslope within the existing range. In a similar study by Bässler et al (2008) variation in species composition of conifer woodland communities in Bavaria reported that carabids, birds, fungi, molluscs, spiders and vascular plants all showed variation along an altitudinal gradient. They inferred a strong relationship between temperature and distribution so implying a probable major impact for climate change on these communities that would be ameliorated by uphill movement of species.

Lenoir & al. (2008) compared the altitudinal distribution of 171 forest plant species between 1905 and 1985 and 1986 and 2005 along the entire elevation range (0–2600m) in western Europe (the Western Alps, the Northern Pyrenees, the Massif Central, the Western Jura, the Vosges, and the Corsican range). They showed that climate warming has resulted in a significant upward shift in species optimum elevation averaging 29 meters per decade. They found that the shift is larger for species that are restricted to mountain habitats and for grassy species, which are characterized by faster population turnover. They noted that the average magnitude of change in the optimum elevation of forest plant species across the entire altitudinal gradient [29.4 ± 10.9 m per decade] closely matches the figure observed for the shift of alpine plants above the tree line [27.8 ±14.6 m per decade]. Given the modelled increase of 2°C across Europe by 2050, plants would need to achieve a vertical shift of 75m per decade (environmental lapse rate

is usually of the order 6.5°C per 1000m altitude) to remain in the same temperature zone from year to year.

The floristic composition of the uppermost 10 m of ten high mountain summits in the Bernina area of the south-eastern Swiss Alps was resurveyed, following earlier surveys in 1805 and 1985 by Walther *et al.* (2005) and showed that there was an acceleration in the upward shift of alpine plants suggesting a rapid response of the vegetation to the conditions in the warming decade of the 1990s.

Similar evidence has been reported from the Italian Alps indicating that climate change in the Italian Alps is forcing plants to move to higher altitudes (Parolo & Rossi 2007). They compared historical records (1954–1958) with results from recent plant surveys (2003–2005) from alpine to nival ecosystems in the Rhaetian Alps, N-Italy. The presence of all vascular plant species and their maximum altitude were recorded along a continuous altitudinal transect of 730 m.. They found that that 52 of the plant species surveyed have moved 430m higher than their previously recorded limits in response to a 1.5°C rise in temperature (for a list of these species see Appendix B to their paper). Some of the species had already reached the summit of the mountains, implying that any further pressure to migrate upwards would inevitably lead to extinction.

Changes in the vegetation of the high mountains of the Central Iberian range in Spain over the period 1957–1991, whereby grassland communities of *Festuca aragonensis* characteristic of the orocryozone have been replaced by patches of *Juniperus communis* subsp. *alpina* and *Cytisus oromediterraneus* from lower altitudes have been attributed to the probable consequences of climate change (Sanz-Elorza & al. 2003).

2.3 Plant species as indicators of climate change

Increasingly, calls are being made for the use of indicators to allow scientists and policy makers to assess more readily the impacts of climatic change on biodiversity. Such indicators would also help raise awareness of the biological consequences of climatic warming, and could be used in setting targets for the reduction of impacts and in guiding the implementation of mitigation and adaptation measures (Gregory *et al.* 2009). A scoping project to develop a methodology for the use of plant species as an indicator of the impacts of climate change on biodiversity was commissioned by the European Topic Centre on Biodiversity from the University of Vienna and the results are presented by Pauli *et al.* (2008). Their report focuses on alpine plants which represent a significant proportion of the vascular flora of Europe, and, as discussed below (Sect. 3.1.2), are reported be particularly vulnerable to climatic change, with a loss of around 60% of species by 2080 predicted in one study (Thuiller *et al.* 2005a).r. They used the species data from the 18 GLORIA[5] target regions across Europe, covering some 1000 species of which 687 were selected. The project aims to develop a simplified indicator based on alpine plants by considering the most relevant drivers of climatic change and the most sensitive elevation zones. The work is still in progress.

3. REGIONAL VARIATION IN IMPACTS OF CLIMATE CHANGE IN EUROPE AND WITHIN COUNTRIES

The diversity of plant life in Europe reflects the extraordinary range of climates, geology and soils found on the continent and its islands (Akeroyd & Heywood 1994). The vegetation zones range from the

[5] Global Observation Research Initiative in Alpine Environments whose aim is to establish and maintain a world-wide long-term observation network in alpine environments. The European target regions are: (1) Sierra Nevada (Spain), (2) Central Pyrenees (Spain), (3) Ritondu of Corsica (France), (4) Central Apennines (Italy), (5) Northern Apennines (Italy), (6) Lefka Ori of Crete (Greece), (7) Mercantour–Southwestern Alps (France), (8) Entre mont–Western Alps (Switzerland), (9) Dolomites–Southern Alps (Italy), (10) Hochschwab–Northeastern Alps (Austria), (11) Tatra–Western Carpathians (Slovakia), (12) Rodnei–Eastern Carpathians (Romania), (13) Central Caucasus (Georgia), (14) Cairngorms–Scotland (UK), (15) Dovrefjell–Southern Scandes (Norway), (16) Latnjajaure–Northern Scandes (Sweden), (17) Southern Ural (Russia), and (18) Polar Ural (Russia).

arctic and subarctic tundra and northern coniferous forest to temperate deciduous forest, heaths and grasslands, alpine screes and Mediterranean subtropical forests, steppes and scrub and the impacts of climate change will vary correspondingly. Even within single countries such as France, Spain and Greece, the diversity of habitats and climate zones is remarkable and is reflected in the probable patterns of climate change and plant adaptation. Thus in Spain, plant life is expected to be affected by two antagonistic climatic trends: warming and the reduction in availability of water. This will lead to a significant 'mediterranization' of the north of the Iberian peninsula and a aridization of the south (Abanades Garcia & al. 2007).

If the Macaronesian region, whose endemic species are listed in Appendix 1 of the Bern Convention, is included, a further range of specialized habitats and communities such as the evergreen broad-leaved Laurel forest (laurisilva), the thermophilous forests with *Phoenix canariensis* and *Dracaena draco* and the Euphorbia-rich xerophytic shrubs communities.

One of the broadest attempts to model climate induced changes to distribution of species in the European flora was that by Bakkenes *et al.* (2002) using the proprietary IMAGE 2 model (Alcamo, 1994) based on the IPCC 1992 IS92a scenario reduced to 13 summary variables. They used six of these variables to produce bioclimatic niche models for species included in the *Atlas Florae Europaeae* (Jalas & Suominen, 1972-1994). Although modelling with very few variables further summarised by regression analysis has been criticised (Peterson, 2007) this study has value in its breadth of coverage. Current species densities per 50km grid square vary from >300 to <10 although some of this is believed to be due to under recording in the eastern regions of the *Atlas.* The study suggested species loss per grid square from <10% on the Bulgarian coast and around the Western and northern seaboards to >80% in areas of Spain and Russia. Potential numbers of new species per grid square were also calculated but the areas of greatest increase corresponded to areas of probable under recording in the initial data. Thomas *et al.* (2004) in a global overview of regional studies suggested that between 6% (minimum change and high dispersal) and 29% (maximum change and no dispersal) of Europe's flora would become extinct by 2050.

At a regional level Berry *et al.* (2002) used UKCIP98 scenarios for 2020 and 2050 to model change in distribution of the UK biota using 40 plant and eight animal species. Using a neural network approach and seven interpolated variables they found species either to lose distribution at the southern end of their range, to show no change or to gain distribution at the northern edge of their range. These results show a pattern typical across Europe, a general northward shift in the modelled distribution of species with gains, stasis and loss based on whether the species began in the southern, central or northern element of their European distribution.

3.1 Regional impacts

According to the EC (CEC 2007) the most vulnerable areas in Europe to climate change are:

- Southern Europe and the entire Mediterranean Basin due to the combined effect of high temperature increases and reduced precipitation in areas already coping with water scarcity.
- Mountain areas, in particular the Alps, where temperatures increase rapidly leading to widespread melting of snow and ice changing river flows.
- Coastal zones due to sea level rise combined with increased risks for storms. Densely populated floodplains due to increased risks for storms, intense rainfall and flash floods leading to widespread damages to built-up areas and infrastructure.
- Scandinavia where much more precipitation is expected and a larger part in the form of rain instead of snow.
- The Arctic region where temperature changes will be higher than in any other place on Earth.

To these we can add the islands of Macaronesia which are vulnerable to an eastwardly shift of the Azorean anticyclone that would diminish the frequency and intensity of the northwest trade winds with consequential effects on the unique Laurel forest zone and causing its downward displacement and increasing aridity in the coastal zone as result of increase in the prevailing easterly winds from Africa.

3.1.1 The Mediterranean region

Several European countries border the Mediterranean, one of the world's main centres of plant of diversity (Davis & al. 1994; Heywood 1998), housing c. 10% of the world's higher plant species, about half of them endemic to the region[6] (Heywood 1995; Quézel & Médail 1995). Recent reports on Climate Change such as IPCC (2007), the Stern Report (Stern, 2007), and Confronting Climate Change (Bierbaum, 2007), have identified the Mediterranean region as highly susceptible to change. It is widely agreed that the flora and vegetation of the Mediterranean region are the most vulnerable in Europe to climate change because of their sensitivity to drought and rising temperatures and the fact that they are already under stress (EEA 2005; Schröter & al. 2005; Berry & al. 2007a,b; Giannakopoulos & al. 2005). The Mediterranean region is currently the focus of a great deal of attention because of its unique climatic characteristics: its semi-enclosed sea, elongated shape, large topographic contrasts and climate gradient from mid-latitude to subtropical and its great sensitivity to climate change Lionello *et al.* (2008). Added to this are the impacts the region has suffered from anthropogenic change over thousands of years. Temperature scenarios for the Mediterranean have recently been estimated by Hertig & Jacobeit (2008) whose assessment indicated that even with a high level of uncertainty regarding the regional distribution of climate change in the region, 'substantial changes of partly more than 4^{o} C by the end of the century have to be anticipated under enhanced greenhouse warming conditions'. This will have a serious impact on the evaporation rates and water budget and availability in the region which is likely to be at increased risk of water shortages, forest fires and loss of agricultural land.

The population of the coastal states of the Mediterranean has doubled in the last 40 years to 450 million in 1999 and is expected to reach over 600 million by 2050. In addition, the Mediterranean is the leading tourist destination in the world with the twenty countries bordering the Mediterranean Sea attracting over 30% of world tourism. The 46,000 km long coastal zone is visited by about 183 million tourists during the 3-month summer season and an additional 100 million domestic tourists bring the total up to about 280 million visitors a year and projected to reach 350 million by 2015. Over 12 million tourists visit the Mediterranean islands each year. 25,000 km of the coastline is already urbanized and have already exceeded a critical limit.

The Mediterranean region plays a unique role in the context of climate change and its effects on biodiversity as it acts as a barrier to migration of many plants from south to north within the time-scale of concern. Because of the lack of a comparable Saharan hinterland that characterises the corresponding North African climatic belt, a novel climate will develop in southern/Mediterranean Europe as a result of climate change and it is difficult to envisage the kind of vegetation that will occupy this in the absence of large-scale migration of species from North Africa although long-distance dispersal will allow some species to migrate. It will be vulnerable to weedy or invasive species: existing ones will be expected to persist or expand their distributions and new ones take hold.

Another factor is the possibility that the Mediterranean region has already been subjected to a major extinction event in an earlier period so that it is more resistant now to further climate change (Greuter 1995). This is moderated however by the fact that so many Mediterranean species are of restricted distribution and confined to mountains or islands or both. A considerable percentage of Bern Convention species occur in the Mediterranean parts of Europe, many of them, as discussed below, mountain species occurring in small populations in specialized habitats and many of them of threatened status. The prospects for their survival are poor. Mediterranean mountain ecosystems will likely experience significant climatic change during the 21st century and will be subjected to an intensive transformation in terms of structure, functions, and services, even assuming the most conservative estimates (Nogués-Bravo *et al.* 2008).

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[6] Greuter (1991), in an analysis of the flora based on the published volumes of Med-Checklist, gives an extrapolated figure of nearly 37.5% considered to be locally endemic (i.e. confined to a single area) and 63.5% endemic to the region covered by Med-Checklist.

3.1.2 Mountain and alpine zones

Many of the Bern Convention plant species occur in mountain[7] or alpine zones which are not only species-rich but subject to particular climatic stresses and particularly sensitive to anthropogenic climate change (Nogués-Bravo & al. 2007, 2008; Thompson 2005; Thuiller *et al.* 2006). As already noted, recognition of the importance of the mountain regions of Europe led to the development of the GLORIA-Europe project, the European dimension of the Global Observation Research Initiative in Alpine Environments, a 5th RTD framework programme of the EU.

It is estimated that alpine species that occur in Europe's high mountains account for some 20–25% of Europe's total plant diversity (Grabherr et al. 2007; Nagy & Grabherr 2009). Notable concentrations of montane species are found in the European Alps, the Appennini and Alpe Apuane, Italy, the French and Spanish Pyrenees, Sierra Nevada, Baetic and Subbaetic sierras of Spain, the Lefka Auri (White Mountains), Crete, Mount Olympus and the mountains of southern and central Greece, Troodos mountains, Cyprus. It is not surprising, therefore, that a considerable number of studies has been made of the impacts of climate change on montane regions in Europe.

The EEA (2008) has suggested that 60% of mountain plant species face extinction, presumably based on the conclusions of a distribution modelling study by Thuiller *et al.* (2005a) that mountain species, located near the Mediterranean basin, were disproportionately sensitive to climate change, losing potentially up to 60% of their species and while this may prove overly pessimistic, there can be no doubt that the prospects for many of them look bleak. Already, as we have seen, there is evidence of the movement of plants up the mountains in various parts of Europe, with some of them having already reached the summit and with nowhere else to migrate to. Many montane species occur in small, isolated populations that are less able to survive because they lack the genetic variability needed to adapt to changing conditions such as climate change or disease. They often occur in unique communities in specialized habitats. Rupicolous species in particular are often restricted to quite specific niches or microhabitats (Thompson 2005) which poses problems not just for their coping with climate change but even for conservation under present conditions. They are also frequently at risk from grazing by goats and sheep. Many of them will be unlikely to be able to migrate even short distances in a few decades so that management interventions may be needed to facilitate their dispersal into suitable areas (Farris *et al.* 2009).

It is not possible to give a comprehensive list of such species but examples of endemic Berne Convention Appendix I species include *Artemisia granatensis*, *Brassica hilarionis*, *B. insularis*, *B. macrocarpa*, *Brassica sylvestris* subsp. *taurica*, *Bupleurum kakiskalae*, *Coincya rupestris*, *Erigeron frigidus*, *Hormatophylla pyrenaica* (*Alyssum pyrenaicum*), *Lotus callis-viridus*, *L. eremiticus*, *L. maculatus*.

As a consequence of the difficulty of conserving habitats such as cliff faces, many such species are not adequately protected and it is only their inaccessibility that affords them some degree of protection. The problems facing them in a period of accelerated climate change are not just the ability or not to adapt to the new climatic envelopes or whether they will be able to migrate or not to areas predicted to be suitable for them climatically and ecologically but whether suitable niches exist into which they might be able to move. Even when suitable adjacent habitats are available, the ability of some species to migrate to them in the time-scale available is unlikely. The whole issue of niche availability and climate change is discussed below (Sect. 5.1).

As Nogués & al. (2008) note, montane ecosystems and human activities are intimately linked and in mountainous areas, lower regions are affected by settlements and exploitation of forest resources, and zones above the tree line are subject to grazing and anthropogenic fire practices intended to maintain grassland and to lower the tree line. As a consequence deforestation is generally most extensive in the

[7] Mountain (or montane) is used here in a general senses while alpine, following Nagy & Grabherr (2009) refers to the zone above the treeline.

lowlands and at high altitudes, with most forest remaining at mid-altitude, while overall human impact is larger in the lowlands and decreases almost monotonically with increased elevation. In common with other parts of the world, human activities have generally affected worldwide the lower and upper slopes more than the mid-altitudinal habitats

The Alps[8].

The Alps have been described as the largest natural region left in Europe and are therefore of major importance to biodiversity conservation. The vascular plant flora of the Alps has been estimated at c. 4500 species of which 750–800 mainly grown above the treeline (Grabherr 2009) and 270 species are endemic to the Alps (Ozenda and Borel 2003). However, biodiversity in Alpine regions is threatened by intensive agriculture, pollution and climate change. The impacts of climate change in the Alps have been reviewed in a report by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU 2007) which noted that there is a consensus on findings that show the following climatic scenario:

- Decrease in the number of ice and frost days; greater warming of winter than summer temperatures; precipitation falling as rain rather than snow.
- Less summer and more winter precipitation; earlier onset of snow-melt, with a resultant shift in maximum run off from spring to winter.
- Greater variability of both temperature and precipitation, with an increased risk of extreme weather conditions.

As noted above, altitudinal shifts in the distribution of many species attributed to climate change has already been reported from several regions of the Alps. By comparison with historical records, it has been shown that species-richness on 30 peaks has increased up to 70%, probably as a consequence of their spread at higher altitudes. While widespread species may be able to withstand temperature rises of 1–2^{o} C, above that level species with restricted distributions above the tree line will experience severe fragmentation of their populations and migration to cooler areas will be virtually impossible for those species that are already close to the summits (Dirnböck *et al.* 2003).

While most attention has been paid to the summits and upper slopes of alpine and other montane regions, the impacts at lower levels also needs to be considered. Vittoz *et al.* (2009) used permanent plots and phytosociological censuses to study changes in the composition of subalpine grasslands in two separate regions in the northern Swiss alps. They found that while rapid species colonization may be induced by climate change on high mountain summits when it is facilitated by incomplete ground cover, or by structural changes, the dense vegetation cover of the subalpine grasslands limited the chance of new herbaceous species establishing themselves so that only limited changes in the vegetation were observed. The results agreed with Körner's thesis (2005) that future changes in the vegetation of such areas will be influenced more by land management than by climate change.

With the Alpine regions coming under the control of seven governments, the need for countries to work together to develop biodiversity conservation strategies for the Alps is paramount. An example of such cooperation is the Ecological Continuum Project[9](Ohler & al. 2008) which has as its aim the development of a joint methodology for protection and enhancement of biodiversity in the Alps.

Sierra Nevada

The Sierra Nevada in Spain is the most important centre of plant diversity in the western Mediterranean, housing some 2100 vascular plant species that represent about 30% of the flora of

[8] The European Alps are found in Austria, Italy, France, Switzerland, Germany Slovenia, Leichenstein and Monaco, the countries which are members of the Alpine Convention (http://www.alpconv.org/)

[9] The Ecological Continuum Project is run by a consortium of four organisations: ALPARC (Alpine Network of Protected Areas), CIPRA (International Commission for the Protection of the Alps), ISCAR(International Scientific Committee on Research in the Alps) and the Alpine Program of WWF.
See:http://econet.scnatweb.ch/index.php/initiatives/the-ecological-continuum-project-mainmenu-62 S

peninsular Spain in only 0.4% of the surface of that area. It also represents about 7% of the flora of the Mediterranean region area in only 0.01% of its surface area (Lorite *et al.* 2003). According to Blanca and Lorite (2001) 123 of these species are threatened: 8 critically endangered, 20 endangered and 95 vulnerable *sensu* IUCN. 80 species are endemic to Sierra Nevada, most of them on the upper slopes in screes and cliffs and some of these species are extremely rare or localised such as *Senecio elodes, Erodium astragaloides, Odontites granatensis, Hippocrepis prostrata, Artemisia granatensis, Erigeron frigidus*, several of them on Appendix 1 of the Bern Convention. Others such as *Gentiana boryi, Plantago nivalis, Ranunuculus acetosellifolius, Leontodon microcephalus,* grow in moist areas such as moist pastures, streams, glacier runoffs.

More than 30 of the threatened species in Sierra Nevada have populations of fewer than 500 individuals such as *Acer monspessulanum, Adonis vernalis, Andryala agardhii, Artemisia alba* subsp. *nevadensis* (<300), *Draba dubia* subsp. *laevipes, Epilobium angustifolium, Erodium daucoides, Kernera boissieri, Ononis cristata, Ribes uva-crispa, Senecio eriopus, S. quinqueradiatus,Sibbaldia procumbens, Sorbus torminalis, Sparganium angustifolium* and *Taxus baccata,* while some scarcely reach 200 individuals, as in *Betula pendula* subsp. *fontqueri, Cephalanthera rubra* (<100), *Epipactis atrorubens* (<100), *Ilex aquifolium, Limodorum abortivum, Salix hastata* subsp. *sierrae-nevadae* (<50), *Sorbus hybrida* (<25) (Blanca &Lorite 2001).

3.1.3 Mediterranean Islands

The Mediterranean encloses some 5000 islands, ranging from islets of a few square metres to large islands such as Sicily with 25 700 km^2. The larger islands in particular house many endemic species, with an average rate of endemism of 10% and while the smaller islands are less rich, they frequently share endemics with other islands (Delanoë *et al.* 1996). A summary of the then state of conservation and threats to the island floras (see Delanoë *et al.* 1996: 3.3.1) prepared for a meeting in 1993[10] which led to the creation of the IUCN SSC Mediterranean Island Plant Specialist Group (MIPSG). Globally threatened taxa (based on the earlier IUCN criteria) are summarized in Box 3.2.

Box 3.2: Globally threatened taxa on large Mediterranean islands (from Delanoë *et al.* 1996)

			% of threatened				
Island(s)	Ex	E	V	R	I	Total	taxa
Balearics	1	10	14	43	1	69	5
Corsica	1	8	27	10	1	47	2
Sardinia	11	30	21	1	63		3
Sicily	1	11	26	45	4	87	3
Crete		11	61	118	3	193	11
Malta	1		1	10	4	16	2
Cyprus		9	14	22	6	51	3

Threatened taxa as % of the total number of island taxa
Source: WCMC, Donna Smith, pers. comm. (1996)

These endemic species are often very localized and the populations comprise a small number of individuals, which makes them particularly susceptible to extinction. The 'Top 50' of these have been selected by the IUCN MISPG (Montmollin & Strahm 2005) (Table 3.3). Most (46) of these are classified as Critically Endangered (CR) and many of them (indicated by an asterisk in Table 3.3) are Bern Convention Appendix 1 species. About half of them have some of or all their populations represented in protected areas although the level of protection is not always adequate and threequarters of them come under some form of legal protection but again not always adequately enforced. Most of them must also be considered to be at serious risk from climate change in addition to the threats they already face and their future conservation prospects are bleak. Complementary conservation efforts such as *ex situ* will be

[10] See Olivier *et al.* 1995

needed and samples of about half of these species are found in botanic gardens or seed banks but in many cases the number and quality of the samples is inadequate to maintain their genetic diversity or for reintroduction programmes. As discussed below, a detailed and critical review of the state of *ex situ* conservation for Europe's threatened species is urgently needed.

Table 3.2 Top 50 Mediterranean island plants

Aeolian Islands
Silene hicesiae
Alborán
**Diplotaxis siettiana*
Balearic Islands
**Apium bermejoi*
Arenaria bolosii
Brimeura duvigneaudii
**Euphorbia margalidiana*
Femeniasia balearica
Ligusticum huteri
**Lysimachia minoricensis*
**Naufraga balearica*
Columbretes
Medicago citrina
Corsica
**Anchusa crispa*
Biscutella rotgesii
**Centranthus trinervis*
Limonium strictissimum
Crete
**Anthemis glaberrima*
**Bupleurum kakiskalae*
**Convolvulus argyrothamnos*
Horstrissea dolinicola
Cyprus
**Arabis kennedyae*
Astralagus macrocarpus subsp. lefkarensis
**Centaurea akamantis*
**Delphinium caseyi*
Erysimum kykkoticum
Salvia veneris
**Scilla morrisii*
Greek Islands
**Aethionema retsina*
**Allium calamarophilon*
**Consolida samia*
Minuartia dirphya
Polygala helenae
Saponaria jagelii
Malta
**Cheirolophus crassifolius*
**Cremnophyton lanfrancoi*
**Helichrysum melitense*
Sardinia
Aquilegia barbaricina
Aquilegia nuragica
**Lamyropsis microcephala*
Polygala sinisica
**Ribes sardoum*
Sicily
**Abies nebrodensis*
**Bupleurum dianthifolium*
Bupleurum elatum
Calendula maritima
Hieracium lucidum
Petagnaea gussonei
Pleurotus nebrodensis
Viola ucriana
Zelkova sicula
Tuscan archipelago (Capraia)
Centaurea gymnocarpa

* Listed in the Bern Convention Appendix 1

Crete

The island of Crete has a remarkably rich vascular flora of some 1,800 native species, with about 180 of them endemic, making it the region of Greece with the highest endemism. Many of these species exist as small populations which are restricted to one or few cliffs or mountain sites. Rare endemics such as *Androcymbium rechingeri, Bupleurum kakiskalae, Nepeta sphaciotica, Hypericum aciferum* are considered to be critically endangered due to tourism, farming, sheep and goat grazing, uncontrolled access, resulting in trampling and plant collection, fires and finally habitat alteration through deforestation and drainage. More than 100 endemic plant species are present on the Lefka Ori (White Mountains) massif, with 30 of them endemic to the area (Turland *et al.* 1993) and considered as rare and threatened with extinction according to the Red Book of Rare and Threatened Plants of Greece (Phitos *et al.* 1995). Within the Lefka Ori, the Samaria Gorge, that was proclaimed as a National Park by the Greek Government in 1962 and a Biosphere Reserve by UNESCO in 1981. The Gorge is famous as a mountainous limestone area with steep rocky slopes and canyons up to 600 m deep. The area is characterized by the presence of 16 habitats of the European Habitat Directive,7 of which are of priority. The vascular flora consists of more than 500 species of trees, shrubs and herbs, 77 of which are endemic species, 37 rare, and 6 vulnerable (Vogiatzakis et al. 2003).

Six plant species listed in the Bern Convention Appendix 1 and Annex II of the Habitat Directive (EEC/92/43) have been recorded at the Lefka Ori site[11]: *Bupleurum kakiskalae* (local endemic), *Nepeta sphaciotica* (local endemic), *Hypericum aciferum* (local endemic), *Cephalanthera cucullata*, *Zelkova abelicea* (the unique endemic tree of Crete), *Origanum dictamnus*, and an additional species, *Centaurea lancifolia*, is included in Annex IV.

Troodos and Pentadactylos, Cyprus

Cyprus is amongst the richest countries for plant diversity in Europe. Its flora comprises almost 2000 taxa, out of which 143 are endemic to the island. The most important areas for plant diversity are the two mountain ranges of Cyprus, Troodos and Pentadactylos; the latter hosts 62 endemic taxa, of which 16 are local endemics. Some of these species grow in only a few, small populations and it is these taxa where conservation is most urgently needed. This is largely due to the increase in anthropogenic pressures during the last three years. These areas are now attracting attention from the construction industry, particularly in regions of great ecological importance, making the conservation of local endemics in their natural habitat (*in situ*) difficult (Kadis *et al*. 2007):

Taxon	Conservation Status			
	Appendix II Dir. 92/43/EOK	Appendix I Bern Convention	IUCN 2002	IUCN Top 50
Brassica hilarionis Post	YES	YES	Vulnerable	NO
Delphinium caseyi B.L. Burt	YES	YES	Endangered	YES (CR)
Ferula cypria Post	NO	NO	Rare	NO
Onosma caespitose kotschyi	NO	NO	Rare	NO
Phlomis cypria Post ssp. cypria	YES	YES	Rare	NO
Salvia veneris Hedge	YES	YES	Rare	YES (CR)
Sideritis cypria Post	YES	YES	Rare	NO
Teucrium cyprium Boiss ssp. *kyreniae* P.H. Davis	NO	NO	?	NO

3.2 Coastal zones

Coastal zones in many parts of Europe and especially in the Mediterranean are already severely degraded and much of the plant diversity is at risk. In C. and W. Europe where endemism is low a small number of endemics are confined to coastal areas, and lake shores. A detailed assessment of the

[11] http://cretaplant.biol.uoa.gr/docs/A5_Interim_Report.pdf

vulnerability of terrestrial and coastal habitats and species in Europe to climate change constitutes Annex 2 of the BRANCH project Final Report, Planning for biodiversity in a changing climate (Berry *et al.* 2007a). Their main findings were that:

> 'Intertidal coastal habitats will decline everywhere in Europe if the policy of 'holding the line' of existing sea defences continues. The most vulnerable intertidal habitats are around the Black Sea, Mediterranean and the Baltic. Saltmarsh and mudflats on these coasts are likely to disappear as sea-levels rise, reducing their coastal protection functions. The threat to saltmarsh and mudflats throughout Europe will increase during this century, particularly under high emissions scenarios. The length of coastline in North West Europe that has a high vulnerability to sea-level rise is predicted to increase by 46% under the 2080s high emissions scenario'.

In the Mediterranean, habitat destruction through urbanization and other tourist development, fires and the growing extent of intensive cultivation in plastic greenhouses[12], is already affecting not just individual species but plant communities such as the spiny matorral with *Maytenus senegalensis* subsp. *europaea* and *Zizyphus lotus* which occur in frost free zones up to 400m especially in the provinces of Almería and Granada. Although these communities are the subject of a programme of conservation by the Environment Agency of Andalucía, they remain vulnerable to the effects of future climate change.

The problems of preserving sandy beach ecosystems against the effects of climate change are reviewed by Schlacher *et al.* (2008). The main impacts anticipated are:

- Rise in sea levels and the consequent loss of beaches which will severely affect coastal habitats and communities
- Extreme weather events causing more powerful waves which will increase beach erosion
- Changing patterns of precipitation – more floods, altered flow of fresh water, which will affect beach communities and changes in the ENSO (El Niño-Southern Oscillation) events which may affect beach ecosystems

3.3 Macaronesian islands

The flora and vegetation of the Macaronesian islands are highly distinctive with a unique combination of North Atlantic, Africa and Mediterranean elements and have high levels of endemism. The Bern Convention Appendix lists 160 species of vascular plants for the region. The Macaronesian region contains 207 SCIs and hosts around 19% of the habitat types in Annex I of the Habitats Directive.

3.3.1 Canary Islands

The Canary Islands have a flora of some 1992 species of which 21% are endemic. Of the 515 species listed in the latest Red List (Moreno *et al.* 2008) 247 species are at high risk (EX,CR, EN). The flora and vegetation of the islands has been severely impacted: urbanisation and tourist development has destroyed or fragmented the dune communities and coastal forests of *Tamarix*; the highly distinctive low-lying *Euphorbia* scrub has also been affected by urbanisation and by pasture; most of the thermophilous forests and a large part of the Laurel forests have been lost to deforestation. In addition invasive species have caused severe damage (Petit 2008).

Climate change is not considered to be the primary threat to biodiversity in the Canary Islands, although predicted changes in the wind direction and the consequent changes in temperature and precipitation will seriously affect the remaining Laurel forests which will be reduced in extent or possibly displaced to favourable areas (Del Arco 2008). The lower-zone *Euphorbia balsamifera* and *E. canariensis* scrub communities are expected to expand upwards to some degree, subject to the

[12]There has been a rapid increase in protected cultivation in the Mediterranean in recent decades and it now occupies 143,000 ha of greenhouses (Castilla 2002). In the province of Almería (Spain), in the 'sea of plastic' (Mar del Plástico), more than 20 000 ha of traditional agriculture have been converted into protected or greenhouse cultivation in just 6 years.

limits imposed by increased urbanisation. The high altitude ecosystems are likely to suffer from the effects of rising temperatures and some species such as *Bencomia montana* and *Rhamnus integrifolia* with small populations will be at risk as will several rupicolous species such as various species of *Aeonium* which may not be able to migrate to other suitable habitats in a short timescale. The coastal vegetation and dunes will be seriously affected by rising sea levels. Another risk from climate change is the expansion of existing invasive species and the introduction of new ones. For example, the African *Pennisetum setaceum* which is already established in arid zones of the islands is likely to extend its range (García–Gallo *et al.* 1999).

3.3.2 Madeira

In Madeira the Laurel forests are better conserved than those in the Canary Islands. The flora consists of some 500 species of which 143 are endemic (Jardim & Francisco 2000). The most characteristic vegetation is the Laurel forest, rich in endemic species, which today cover some 15 000 ha or 16% of the island and these are the communities most vulnerable to climate change, especially in the intensity of the north Trade Winds. Other threats are from species which although not until now invasive are able to benefit from the changing climate and are beginning to spread and invade the native forests.

3.3.3 Azores

The Azores have suffered major habitat loss, mainly through agricultural development in recent years largely as a consequence of the availability of agricultural subsidies after entry into the EU. The Laurel forest has been largely destroyed with only 2% remaining and invasive species such as *Cryptomeria japonica* and *Pittosporum undulatum* pose a major threat to the native biota. The flora comprises c. 947 species of which 68 are endemic (c. 7 %)

4. CURRENT STATUS OF PLANT DIVERSITY IN EUROPE: THE BASELINE

The flora of Europe is generally well known both at a country level – for most countries there is a recent Standard Flora[13] – and on a continental scale *Flora Europaea* (Tutin & al. 1964–1988; Tutin & al. 1993) served as a floristic synthesis which was widely adopted as a standard treatment, for example by the Standing Committee of the Council of Europe, and used as the taxonomic basis for Bern Convention Appendix 1 and the Habitats Directive. For the whole of the Mediterranean region, *Med-Checklist* (Greuter et al. 1984–89; Greuter 2009) provides a critical, synonymic checklist of genera, species and subspecies, with country-by-country distributions for many families; and the Euro+Med PlantBase project has compiled a database of the combined European and Mediterranean territories although not yet fully revised and edited. For distributional and mapping data of vascular plants, *Atlas Florae Europaeae*, although not complete is an invaluable resource (see Sect. 3): between 1972 and 2007, the Committee and *Societas Biologica Fennica Vanamo* published thirteen volumes of the Atlas, with altogether 2559 pages and 3912 maps (Jalas *et al.* 1972-1999, Kurtto *et al.* 2004–2007). To date, the maps cover the families which include over 20% of the vascular plants of Europe (Lycopodiaceae – Rosaceae, p.p.). The latest volume 14 (Rosaceae: *Alchemilla* and *Aphanes*) was published in December 2007 (> 4,300 taxa). The principal aim of the AFE is to provide maps with taxonomic notes of species and subspecies to complement the published volumes of *Flora Europaea*. In effect, the taxonomic notes and the maps constitute a partial revision and updating of the taxonomy and distributions given by *Flora Europaea*. They provide an invaluable baseline of information which will be important in predicting future distribution patterns as a consequence of climate change.

Despite these various initiatives no precise figure for the vascular flora of Europe can be given but the SynBioSys Europe[14] checklist database (Hennekens and Schaminée 2001) includes 15 974 species, including 1,909 apomictic species (Ozinga & Schaminée 2005) although it is still provisional. Yet a comprehensive and accurate taxonomic checklist is an essential basis for preparation of Red Lists

[13] Standard Floras are those Floras that are the generally acknowledged by the botanists in the country or region as the most reliable sources of information on the plants that occur there and consequently are the most widely used. Lists of Standard Floras for Europe are given by Tutin & al. (1964–1988; 1993) and for the Mediterranean Region by Heywood (2003).

[14] SynBioSys Europe, an initiative of the European Vegetation Survey (EVS) (Schaminée & al. 2007), is an information system for the evaluation and management of biodiversity among plant species.

which in turn is needed for the establishment of ecological networks such as PEEN. Ozinga & Schaminée (2005) extracted from the database a list of 2968 Target Species based on meeting one of the following criteria:

- *Legal protection*: Listing of species in international conventions (species for which European legislation imposes to its contracting parties specific measures);
- *Threat*: Listing on IUCN Red lists (species whose survival in the near future is threatened on a global level, based on a combination of two criteria: rarity and trend);
- Geographical distribution (endemism): European endemics (species for which the global distribution is restricted to Europe or that are highly characteristic for Europe

4.1 Threatened species

Despite a number of initiatives, it is remarkably difficult to obtain accurate figures of the numbers of threatened species in Europe. The most commonly used system for assigning conservation status of species is that of the IUCN Red List programme, although threat management strategies will usually take into account other factors. According to the current IUCN Red List (http://www.iucnredlist.org/) some 166 plant species are currently recorded as Threatened in Europe: CR 65, EN 35, VU 66. This compares with the 1997 IUCN Red List of Threatened Plants which, using the earlier categories of threats, listed a much larger number. An analysis of the 1997 list, supplemented by a literature review of 48 Red Book/Lists from 36 countries and consultation with experts was undertaken by the Conservatoire Botanique National de Brest in partnership with the Council of Europe and at the request of the European Topic Centre on Nature Protection and Biodiversity of the EEA (Richard & al. 2004; Buord & Lesouëf 2006). The latest version showed that 763 European plant taxa can be considered as extinct (EX/EW) or close to extinction (CR). 75 no longer exist in the wild. The analysis also showed that of 663 taxa listed in Annex I of the Bern Convention, only 169 correspond to taxa assessed as close to extinction (22.1% of 763 taxa). In the case of the EU Habitats Directive, of 597 taxa (Annex II & IV), only 147 correspond to taxa assessed as close to extinction (19.3% of 763 taxa). Although these figures need updating, the analysis concludes that European legal instruments do not protect adequately taxa for which Europe has a global responsibility (Box 4.1). The information on each taxon is maintained in a database which includes data on threatened status, distribution, cultivation in botanic gardens, nature of threats, legal protection, and recovery programmes.

The regional distribution of these species is shown in Table 4.1 (from Buord & Lesouëf 2006):

Region	No. of extinct or critically endangered taxa	% of globally extinct or critically endangered taxa in pan-Europe
Balkan peninsula	160	21,0
Iberian peninsula	162	21.2
Macaronesia	169	20.8
Italian peninsula	135	17.7
Rest of Europe	147	19.3

BGCI has developed a consolidated list of European threatened species as a step towards a formal Red List (Sharrock & Jones 2009). Compiled on a database, the list consists of national Red List data from 30 European countries and includes over 16,000 country records covering around 9,600 species. The European threatened plants list that has been developed (based on national Red Lists and species distribution data) contains 1,917 taxa (species and sub-species). It includes apomictic species when these are included on national lists. As well as national Red Lists, additional data were obtained from IUCN global Red Lists (1997 and 2008), Habitats Directive, Bern Convention, the database of most threatened plants in Europe (European Topic Centre) and a list prepared by Alterra for PEEN (Ozinga & Schaminée). 90% of taxa on the list are single country endemics and the countries with the highest number of taxa on the list are – Italy (586 taxa), Spain (432), Greece (317) and France (171). A further 2,408 taxa have been identified as of conservation concern (information from the sources above), but have not been included on the list.

For this report we have compiled a list of Bern Convention species showing their current IUCN Red List status, their Red List assessment according to Buord & Lesoëuf (2006), availability of a recovery plan and an indication of the number of distribution points available for niche modelling (Annex 1). An examination of the Annex shows that:

- Of 542 plant taxa listed in the Bern Convention only 30 (<6%) are listed on the current IUCN Red Data list (IUCN 2009) although a review of 619 (excluding Macaronesia) plant taxa deserving IUCN categorisation of CR or above by Buord & Lesouëf (2006) included 88 Bern list species.
- Despite the critical need for data on Bern Convention species, only 115 taxa (21%) have 20 or more distribution points accessible via the GBIF portal, the minimum usually needed for bioclimatic niche modelling to be feasible. The 619 reviewed by Buord & Lesouf (2006) fared worse with only 21 (3%) including sufficient data.
- 280 of the taxa listed by Buord & Lesouf (2006) have a recovery programme or legal protection for the species in at least part of its native area but only 64 Bern convention species do.

Box 4.1 Legal protection of European plant species

In terms of legal protection at a European level the situation is summarized by Ozinga and Schaminée (2005): The Bern Convention lists 642 vascular plant species (4.6 %), while the Habitats Directive lists 484 plant species (3.4 %). Together both legal listings cover 774 species (5.5 %). From the 1,939 species that are globally threatened, 79 % are not listed by the Bern Convention or the Habitats Directive. This result shows that the European legal instruments provide no adequate protection for many threatened vascular plant species.

More accurate and updated figures are available for some individual countries. In Spain, for example, the latest edition of the Red List of the vascular plant flora (Moreno 2008) lists 1196 threatened taxa (CR, EN, VU) compared with 1128 in the previous edition published in 2000 (VV.AA 2000) while initiatives are in hands to revise the Italian Red List (Rossi et al. 2008).

4.2 Red Listing and climate change.

The current IUCN Red List criteria are designed for classification of the widest set of species facing a diversity of threatening processes but do not take climate change as such into account and Akçakaya *et al.* (2006) warn of the dangers of their misuse for this purpose. IUCN has, however, listed five groups of traits that are believed to be linked to increased susceptibility to climate change:

- Specialized habitat and/or microhabitat requirements
- Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle.
- Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change.
- Dependence on interspecific interactions that are likely to be disrupted by climate change.
- Poor ability to disperse to or colonize a new or more suitable range.

These have only been applied to a small number of taxa so far although a list of Bern Convention Appendix 1 species impacted by climate change has been extracted from the Brest database (Table 4.2). Consequently the current Red List status of species can only be regarded as valid in the short-term and all current assessments will need to be reviewed and updated as a matter of urgency to take into account climate and other aspects of global change if they are continued to be used as part of any triage system. Niche modelling can be used to estimate change in potential geographic range (category B, 1 & 2) although there may be lag between loss of optimal niche and loss of the individuals (Yesson & Culham, 2006a,b). Local extinction may show a step change rather than gradual change once a certain threshold of change is reached (Best *et al.* 2007).

4.3 Tree species

Many important tree species are already threatened or vulnerable (Newton & Oldfield 2008[15]) and are likely to be very susceptible to further climatic shifts. These include the relict species *Abies pinsapo*, whose communities (pinsapares) constitute one of the most characteristic woody formation in Spain. *A. pinsapo* is largely confined to Spain and occurs in small areas of the Serranía de Ronda y Sierra Bermeja (Málaga), and Sierra de Grazalema (Cádiz). It is at risk from fire, pests and diseases, grazing and wild herbivores and genetic isolation of the populations.

Even more restricted is the Sicilian fir, *Abies nebrodensis* which is reduced to a population of fewer than 29 adults and 20 saplings, according to a recent survey, in the Riserva Integrale in the Parco delle Madonie in Sicily. Conservation of *Abies nebrodensis*, both *in situ* and *ex situ* – to

Table 4.2 Bern Convention Appendix 1 species impacted by climate change (Buord 2009 pers.comm. to vhh)

Abies nebrodensis (Lojac.) Mattei
Andryala levitomentosa (E. I. Nyarady) P.D. Sell
Anthyllis lemanniana Lowe
Arabis kennedyae Meikle
Arenaria nevadensis Boiss. & Reuter
Astragalus tremolsianus Pau
Berberis maderensis Lowe
Campanula bohemica subsp. *gelida* (Kovanda) Kovanda
Cochlearia polonica A. Fröhl.
Delphinium caseyi B.L. Burtt
Erucastrum palustre (Pirona) Vis.
Euphorbia stygiana subsp. *santamariae* H. Schaefer
Hymenophyllum maderense Gibby & Lovis
Kunkeliella canariensis Stearn
Lamyropsis microcephala (Moris) Dittrich et Greuter
Laserpitium longiradium Boiss.
Musschia wollastonii Lowe
Naufraga balearica Constance & Cannon
Nepeta sphaciotica P.H. Davis
Orchis scopulorum Summerh.
Petagnaea gussonei (Sprengel) Rauschert
Poa riphaea (Asch. & Graebn.) Fritsch
Primula wulfeniana subsp. *baumgarteniana* (Degen & Moesz) Ludi
Ranunculus kykkoensis Meikle
Sambucus nigra subsp. *palmensis* (Link) Bolli
Scilla morrisii Meikle
Senecio elodes Boiss.
Veronica oetaea L.-A. Gustavsson
Viola paradoxa Lowe

conserve and manage the existing populations and to expand it through *ex situ* operations – was the subject of a 5 year EU LIFE project, at a total cost of €1 161 535.

5. PREDICTING THE IMPACTS OF CLIMATE CHANGE ON PLANT DIVERSITY IN EUROPE

5.1 Introduction

The tools available to us for predicting the impacts of climate change on the future distribution of plants and ecosystems are limited. Basically for each area or region we wish to know:

[15] They summarize the results of ten recent assessments of different groups of trees, covering more than 2500 species, and estimate that a mean of 42% were classified as threatened.

- which species will be able to track their climate envelopes as they move
- which will not be able to migrate and why (lack of dispersal capacity or reproductive capacity, lack of suitable niches, etc.),
- what the physical (climate-soil) conditions in these new climate envelopes will be,
- what are sources of potential immigrants (both native and non-native) for many regions, i.e. where will the species that occupy the new habitats come from,
- what the biotic diversity will be, i.e. what combinations or assemblages of species (plants , animals, microorganisms, pollinators etc.) will grow there,
- will the novel (emerging) assemblages be able to provide similar values of ecosystem services (including pollinators) as those that they replace?

In response to climate change, plants have three possibilities: adapt, migrate or become extinct. Most current predictions of the future migration of plants use the 'climate envelope' or bioclimatic modelling approach in which projected future distributions are based on the current climate in the species' native range. The current distributions of species are the result of historical factors and complex interactions between biotic and abiotic factors in the environment, not just climate (Ibañez & al. 2006; Pearman et al., 2008a,b; Soberón & Peterson 2005; Soberón 2007; Yesson & Culham 2006a,b, 2009). Climatically, it is a complex of interacting factors not just temperature change but, for example changes in precipitation, evapotranspiration, seasonality, that will determine species' migrations (or not). Also, successful migration will not depend just on climate but on a series of other factors such as the availability of suitable migrants (Ibáñez *et al.* 2008), the dispersal capacity (Vittoz & Engler 2008) and colonization potential of the migrant species (Ibáñez *et al.* 2008), the 'permeability' of the habitats in the new area, ability to grow and compete successfully with the resident species and then spread, some of whose impact is largely unknowable. Some of these issues are discussed in detail below.

An assessment of the vulnerability of species in Europe and its biogeographic regions to climate change was made as part of the BRANCH project (Berry *et al.* 2007a). It used the SPECIES bioclimatic envelope model to project future potential suitable climate space for 389 species that encompass a range of dominant and threatened (sensitive/rare) taxa found within Europe (see Section 5.1). Since this report, data availability for species across Europe has improved steadily, the range of algorithms with which to model has increased and the models of underlying climate have been refined (see section 5.2).

While we can use various types of model to predict the possible migrations of species into 'new' climatic envelopes, what we cannot do with existing modelling approaches is to predict what the new vegetation cover will be nor the overall environmental conditions, in areas impacted by climate change. This applies both to the move-out areas and the move-in areas, a distinction that is not often made but which may be critical in some parts of Europe such as the Mediterranean zone as mentioned above. Since the likelihood of survival and multiplication of migrant species will depend on the environmental context into which they move, not to mention stochastic factors which may intervene, we have to accept that our present understanding of the consequences of climate change is severely limited and sometimes dependent on little more than intelligent speculation. If we add to this the level of uncertainty that still surrounds the details of the extent of climate change and their impact at a local level, much of our planning has to be broadly based rather than site-specific, such as modifying or enhancing our protected area systems, or precautionary such as employing *ex situ* complementarity.

Climate envelope modeling for all European plant species is now needed to provide an estimate of the potential changes to the composition and distribution of the European flora within the next few decades. Direct comparison suggests that species-level modelling provides a slightly more robust prediction than community based modeling for species distributions under climate change (Baselga & Araújo, 2009) at present and that the properties of community based models are still to be fully understood. Europe has both the data and the expertise to conduct species level modelling of its terrestrial flora and such an exercise would entail costs that are trivial compared with the economic impact of likely florisitic changes.

Although bioclimatic modelling is now the commonest approach to predicting the likely response of species to climate change, other non-modelling approaches can be used to assess species vulnerability on the basis of their biological and ecological traits, and other factors, that determine

sensitivity, adaptive capacity and exposure to climate change (Gran Canaria Group 2006; CBDF/AHTEG 2009). Using the criteria suggested by the Gran Canaria Group (Box 5.1), the National Botanic Garden of Belgium undertook a preliminary quantitative assessment of the possible impact of climate change on the native flora with the aim of obtaining a clearer view of possible changes to the composition of the flora. This showed that at least 415 native plant species (30% of the flora) appear to be vulnerable to climate change during the period 2008–2100 (Godefroid *et al.* 2009).

Box 5.1: Criteria for identifying taxa vulnerable to climate change (Gran Canaria Group 2006)

- Taxa with nowhere to go, such as mountain tops, low-lying islands, high latitudes and edges of continents;
- Plants with restricted ranges such as rare and endemic species;
- Taxa with poor dispersal capacity and/or long generation times;
- Species that are susceptible to extreme conditions such as flood or drought;
- Plants with extreme habitat/niche specialization such as narrow tolerance to climate-sensitive variables;
- Taxa with co-evolved or synchronous relationships with other species;
- Species with inflexible physiological responses to climate variables;
- Keystone taxa important in primary production or ecosystem processes and function, and
- Taxa with direct value for humans or with potential for future use.

5.2 Advantages and limitations of niche modelling

> '*Models are simplifications of reality and often begin life by helping researchers to formalize their understanding of a particular process or pattern of interest. Models are thus primarily important aids to research. Difficulties may therefore arise when such theoretical models are used to guide conservation planning, management and to support the formulation of policy decisions (e.g. IPCC). The magnitude of uncertainties in species' range modelling is currently so great that it might lead conservation planners, policy makers and other stakeholders to question the overall usefulness of science as an aid to solve real world problems. Bridging the perceived gap between science and societal needs is of paramount importance if we want to make progress and contribute meaningfully, as scientists, to solving the global environmental change crises*'. Thuiller *et al.* (2008).

The prospect of global climate change has stimulated investigation of the impact of the environment on floral and faunal distribution, speciation and extinction (Thomas *et al.* 2004). Fundamental to the prediction of which species might survive where is the use of bioclimatic niche modelling techniques (Nix, 1986; Guisan & Thuiller, 2005; Peterson et al, 2005; Elith et al 2006). These techniques combine computer based models of the climate now with information on the current distribution of species to establish a bioclimatic (also known as edaphic, fundamental, environmental or Grinellian) niche model. This model of optimal environmental parameters is then fitted to a range of future climate scenarios to establish likely shifts in environmental optima for species.

Niche modelling is a computational process for which there is no single standard approach (Elith & Graham, 2009). Such models are usually based on climatic parameters only and are then called 'Bioclimatic niche envelope' models (often referred to simply as 'Bioclimatic envelopes'). They show the probability of a species occurring in an area based on current distribution and climate data. Models vary in their subtlety from offering simple presence/absence predictions (e.g. BIOCLIM) to those with complex algorithms showing a continuous gradient from 100% to 0% probability of occurrence. One of the earliest, simplest and most widely applied algorithms is BIOCLIM (Nix, 1986), that treats environmental parameters as independent variables that are overlaid to establish the

limits of a niche;, a derivative of this, GARP (Stockwell & Peters, 1999) uses a genetic algorithm approach to generate a probability surface of chance of occurrence. BIOCLIM's models are more conducive to interpretation than some more complex methodologies (Stockman *et al.*, 2006) although comparison with some other techniques demonstrates that more complex algorithms such as MAXENT can have greater predictive value under most conditions (Elith *et al.*, 2006; Phillips *et al.*, 2006). The distance metric based Environmental Distance (DOMAIN, Carpenter et al, 1993) offers a multivariate approach that accounts for elements of co-variation and dependency among variables.

The approach that has now come to the fore uses a maximum entropy approach to modelling (MAXENT, Phillips *et al.*, 2006, Philips & Dudik, 2008). Once niche models have been established, they can be used in conjunction with different climate scenarios and timeframes to estimate past distributions of species (Hugall *et al.*, 2002; Martínez-Meyer *et al.*, 2004; Peterson *et al.*, 1999; Bonaccorso *et al.*, 2006), present (Phillips *et al.*, 2006; Robertson *et al.*, 2001; Stockwell, 2006) and future distributions (Thomas *et al.* 2004; Peterson *et al.*, 2005; Thuiller *et al.*, 2005, 2006, Broenimann *et al.* 2006). Results are dependent on a range of variables including evenness of availability of species distribution data, sufficiency of data, the climate models used and the niche modelling techniques used. Peterson *et al.* (1999) suggest that bioclimatic envelopes are heritable and are conserved across evolutionary time.

Martinez-Meyer *et al.* (2004) demonstrated this using bioclimatic niche models of *Passerina* birds to successfully predict the distribution of sister species. Many researchers are now examining species' climatic preferences across phylogenetic trees (Hugall *et al.*, 2002; Graham *et al.*, 2004; Hardy & Linder 2005; Hoffmann 2005; Yesson & Culham, 2006a,b) and have examined present and past distributions. Most importantly bioclimatic niche models have also been used to predict future distributions, and their impact on extinction risk across lineages (Peterson *et al.*, 1999; Thomas *et al.* 2004). Although models are frequently spoken of casually as preditions, their true role is in providing part of the information base on which predictions of future change are made.

Model development is ongoing and new ranges of parameters and assumptions are being incorporated (Hirzel et al, 2001). The use of migration ability has been used for plants (Yesson & Culham 2006a) and animals (Willis *et al.* 2009 & refs) to convert models of climate suitability to models of likely occupancy based on the species chance of reaching new areas. Studies at fine scale of the movement of metapopulations within species are beginning to demonstrate that gains and losses at the edge of distributions may not balance (Anderson *et al.*, 2009). Physical barriers to upward (mountain top reached) and northward spread (no more land available) as temperatures rise offer immediate threats to some species (Hellmann et al, 2008; Trivedi *et al.*, 2008). .

One approach that avoids the need to make a decision on which modelling algorithm to adopt is 'Ensemble forecasting'. The use of multiple models on the same data allows calculation of the proportion of variation in modelled distribution that is model-choice dependent. The BIOMOD software (Thuiller *et al*. 2003, 2004, 2009) programmed in R offers a suite of algorithms and the analytical means to explore models both for the influence of the component environmental variables (described as 'ecological space' by Thuiller *et al*. 2009) and, through averaging, the ability to assess the variation caused by choice of modelling algorithm (described as 'predictive space' by Thuiller *et a*l. 2009). This approach is still dependent on there being both an appropriate dataset for distribution and on the careful selection of summary climatic variables. Importantly the BIOMOD software includes a range of dispersal options from none to unlimited that allow the modelling process to offer only areas of distribution that the organism could reach. Araújo and New (2007) make a cogent case for the use of ensemble approaches but there are objections due to the risk of compounding errors from poor models. Perhaps one of the most widely used approaches incorporating ensemble modelling is MAXENT (Phillips *et al*. 2006).

Climate influences the broad scale physiognomy of vegetation and determines which species have the potential to grow in an area. There are a range of climate models used both for work in the present and to estimate future scenarios but the predominant ones for use in predictions of global climate change are coupled Atmosphere-Ocean models such as HadCM3 (resolution 2.5×3.75 degrees latitude × longitude and 19 levels of atmosphere) and GFDL CM2.X (resolution 2.5×2 degrees and 25 levels of atmosphere) as adopted by the IPCC (IPCC AR4, 2007). Such models are highly complex and demand high performance computing resources (Slingo *et al.*, 2009; Washington *et al.*, 2009) now at

the petaflop level to allow further advancement. At this resolution models show clear regional patterns in climate but lack fine detail that would identify small-scale climate islands such as mountain peaks. These models are also poor at picking out local scale maritime influence along coastlines where temperatures will be less extreme. The new generation of models that is being developed will use a finer scale resolution of 10' grids that will reduce this problem. Climate models for Europe are already operating at this scale. The new generation of massively parallel computers is finally allowing the bridge between Climate models and Weather models (Slingo *et al.*, 2009). The use of large scale observation systems such as that run by NOAA will greatly advance this cause (McDougall *et al*. 2005). Beyond that it is likely that benefits of using even finer scale models will be offset by habitat factors such as aspect and soil having a greater influence than grid-square to grid-square differences in the climate model output. As detail increases so the issue of data quality will become increasingly pressing and limiting (Chapman *et al.*, 2005).

Data on distribution of species is also limiting for resolution, coverage or both. *Atlas Florae Europaeae* (Jalas *et al.* 1972-1999, Kurtto *et al.* 2004–2007) uses grid squares of approximately 50km^2, a resolution that is coarser than recent climate models however it offers good geographic coverage for the species included. In contrast, data such as those from GBIF can include GPS point references with sub-metre accuracy (although this is unusual) but geographic and taxonomic coverage is very uneven (Stockwell, 2006; Yesson *et al.*, 2007). Bioclimatic niche models are dependent on both climate and distribution data being available at compatible resolutions.

Across the distribution of a species, and certainly for widespread species, there is genetic variation expressed in individual populations or along clines (Thompson, 1999). Such variation is not explicitly accounted for in bioclimatic envelope models but is implicit in the variation in climate parameters over the native distribution of the species. Haplotype variation in Mediterranean tree species has been linked to palaeoclimatic patterns (Magri et al. 2007) but has also recorded the role of historic hybridization events in the genetic evolution of Mediterranean plants (Lumaret & Jabbour-Zahab, 2009; Thompson, 1999 and refs therein). Records of gene flow among Mediterranean species indicates that hybridization is a mechanism that generates change in this flora and novel genetic combinations as well as novel species combinations may become common as habitats experience increasing disruptive change. Given that most species are not genetically uniform, one must therefore be cautious in treating models of migration in response to climate change as an indication that there will be a uniform response even within a species.

6. INVASIVE POTENTIAL WITH CLIMATIC CHANGE.

6.1 Background

One of the most serious consequences of climate change and other components of global change, such as alterations in disturbance regimes, is expected to be the increase in number of invasive alien species (IAS). This has been reviewed by another report in this series (Capdevila-Argüelles & Zilletti (2008). Although IAS do not currently present such a risk as in other parts of the world, they are estimated to cost European economies between EUR 9 600 million and EUR 12 700 million per year each year in damage and control measures (Kettunen *et al.* 2008).

Until recently the issues of alien invasive species have had a relatively low visibility in Europe. The Bern Convention requires the parties '*to strictly control the introduction of non-native species*' (Article 11.2.b) but as Dehnen-Schmutz and Touza (2008) note, there are no controls on imports or exports at the EC level. A major advance was the launch of the European Strategy on Invasive Alien Species in 2003 under the auspices of the Bern Convention although it has been suggested that Europe's practical programmes and coordinated activities on alien invasive species lag behind those of other regions (Hulme *et al.* 2009). Individual European countries have their own legal framework and regulations but current legislation in most EU countries is not adequate to comply with their international obligations under the CBD and the European IAS (for an assessment of individual gaps and recommendations for filling them, see Miller *et al.* 2006).

We do not have an accurate estimate of the number of naturalized or alien invasive species in Europe. An analysis by Weber (1997) of the now somewhat dated information given in *Flora Europaea* (Tutin, Heywood & *al.* 1964–80), produced a figure of 1568 for plant species naturalized in

Europe. In an analysis of the established alien flora of Europe Lambdon & al. (2008) found that there are 3749 naturalized alien species, of which 1969 are native in some region in Europe and 1780 are of extra-European origin and the European Alien Species Database which aims to provide an up-to-date inventory had 11 000 species recorded (February 2008) the majority of them for vascular plants (Olenin and Didžiulis 2009). No comprehensive survey of invasive plant species in Europe has been produced but data are available for individual countries, e.g. North Europe and Baltic countries (NOBANIS[16]), Hungary, Portugal, Spain, United Kingdom, etc. The European and Mediterranean Plant Protection Organization (EPPO) maintains a database on quarantine pests, including invasive alien plants[17], and the European project DAISIE[18] provides distribution of invasive alien plants for Europe.

6.2 Key issues

The assessment, control and prevention of plant invasions is a highly complex subject and involves scientific, technical, economic, social and legal issues. The issues raised by invasive species in conditions of climate change include

- Risk of naturally introduced species becoming invasive
- Extension or changes in the ranges of existing invasive species and changes in their impact
- Introduction and establishment of new invasives
- Understanding vectors and pathways (Hulme et al. 2008)
- Risk assessment risk analysis
- Control strategies
- Preventative action, including horizon scanning for potential new invasives, early warning systems, codes of conduct

Once they become established in a new area, non-native (exotic) species can be are extremely difficult to eradicate or control, suggesting an urgent need for the development of early warning systems to determine the probability of a given species becoming invasive (Andreu and Vilà 2009). It is, however, notoriously difficult to predict which species will become invasive although many attempts have been made. As Hannah (2003) notes, eliminating an invasive species may require lower level of management resources if undertaken prior to climate change taking hold but may be much more expensive or even impossible once climate change spurs the rapid spread of the species.

6.3 Niche modelling and predicting invasives

Invasive species impact on natural ecosystems, agriculture and forestry by altering ecosystem functioning, including the possibility of substantial changes to fire and hydrological regimes (Pimentel et al. 2001; Brooks *et al*., 2004). The potential for invasiveness has been linked to matches in the climate and this has been used as a method to screen for potential invasives (Panetta & Mitchell, 1991; Scott and Panetta, 1994; Curnutt 2000). Bioclimatic niche modelling based on realised distribution assumes that the distribution is in equilibrium and limited by current climate (Phillips et al 2006). Studies of exotic plant species from South Africa that have become invasives in Europe such as *Carpobrotus edulis*, *Senecio glastifolius* and *Vellerophyton dealbatum* (Thuiller *et al.* 2005) have shown that niche modelling can be a powerful tool in the first step screening of invasive potential. Equally, European grass species have become invasive in southern Africa (Parker-Allie et al. 2007, 2009).

The use of distribution data from the native range of a species alone may lead to underestimates of the invasive potential of some species when bioclimatic niche models are compared with realised

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[16] North European and Baltic Network on Invasive Alien Species (NOBANIS): Austria, Belgium, Denmark, Estonia, Finland, Faroe Islands, Germany, Greenland, Iceland, Ireland, Latvia, Lithuania, The Netherlands, Norway, Poland, European part of Russia, Slovakia, Sweden. http://www.nobanis.org/default.asp The database of alien species in NOBANIS will be used to identify species that are invasive at present and species that may in the future become invasive. NOBANIS thus provides the foundation for the future development of an early warning system for invasive alien species.

[17] EPPO Plant Quarantine Data Retrieval System http://www.eppo.org/DATABASES/pqr/pqr.htm

[18] Delivering Alien Invasive Species Inventory for Europe: http://www.europe-aliens.org/

niches (Beaumont *et al.* 2009). A study of five dung beetle species introduced to Australia from South Africa suggests that models based on the native range may perform poorly when a species is removed from its usual biotic environment; only two of the five models proved to act as good predictors for colonization in Australia (Duncan *et al.*, 2009). Actual invasion of a species depends on many other variables such as biotic competition, availability of a niche and the ability to disperse and establish. These factors are less amenable to modelling. The random patterns of extinctions across Europe that will be seen over the next few decades may well result in some native species beginning to spread as if they were alien species as biotic competition changes but these same extinctions may also open up areas for invasion from outside species. The success of invasion will be dependent not just on availability of suitable climatic niches but on the opportunities for dispersal to and within Europe.

6.4 Sources and prediction of invasions

Wilson *et al.* (2009) categorise dispersal into six arbitrary types: leading edge, corridor, jump, extreme long distance, mass and cultivation but admit these categories overlap. These categories provide a useful framework on which to discuss sources of invasive species. Potential invasives in the first two categories will be drawn from the biota surrounding Europe, i.e. Western Asia and North Africa. Those in Asia have an immediate land connection while those in North Africa are separated by the Mediterranean sea. The western edges of Europe are strongly influenced by the Atlantic Ocean which will ameliorate some of the predicted changes in climate. Certainly the western edges will not develop a climate as extreme as central and eastern Europe. It is the centre and east that will be most susceptible to plant migrations from Asia. The climate is similar and land is contiguous. However, this very continuity means there is not a great contrast in floristic composition and change is likely to be an adjustment of the position of the floristic continuum rather than a major change in composition. Candidates for jump and long distance dispersal will be more difficult to predict.

Using colonization of oceanic islands by plant families as a predictive measure of which families will disperse and establish over long distances, leads us to expect a notable discordance in the family level composition of the invasives compared with either the source or the sink flora. Groups such as the Ferns and Compositae have proven their ability both to disperse and establish over long distances. This could lead to a dramatic change in floristic composition with strong gains among some families and substantial loss in others. Loss of the Laurisilva vegetation of North Africa during the formation of the Sahara and its replacement with sparse scrub vegetation may be indicative of the magnitude of change we should expect over the next 50 years in some areas of Europe. Mass dispersal possibilities will depend of the efficiency of quarantine regimes for plant imports. Dispersal can be of the plants that are deliberately moved or of passengers carried with them. There is already a mass international traffic in plants for cultivation and in the form of products such as timber. Unwelcome passengers of this trade have included, the spread of Dutch Elm Disease, lily beetles, box blight (*Cylindrocladium buxicola*) and sudden oak death (*Phytophthora ramorum*), each offering a threat to our flora.

There is good evidence that habitat type is a good predictor of the level of invasion[19]of ecosystems (Chytrý *et al.* 2008). For Europe, Chytrý *et al.* (2009) provide a map estimating the level of invasion by alien plants in Europe, based on quantitative assessment across habitats. Their data set comprised all invasive plants of neighbouring countries and Mediterranean regions, but not yet present in Spain. All plant species listed as invasive in Portugal, France, Italy and in the Mediterranean Basin areas of Northern African countries, as well as, invasive species in other Mediterranean regions of the world (i.e., Chile, California, Australia and South Africa) were included in the list. They showed that the highest levels of invasion were predicted for agricultural, urban and industrial land-cover classes, low levels for natural and semi-natural grasslands and most woodlands, and the lowest levels for sclerophyllous vegetation, heathlands and peatlands. Their main conclusion was that a high level of invasion is predicted for lowland areas of the temperate zone of western and central Europe and low level in the boreal zone and mountain regions across the continent. A low level of invasion is also

[19] *level of invasion* for the actual proportion of alien plant species among all plant species occurring in a given habitat. The level of invasion results from both the habitat properties and the propagule pressure (Chytrý *et al.* 2005, 2008; Hierro *et al.*, 2005; Richardson & Pyšek, 2006). This term is different from *habitat invasibility*, which is the habitat's susceptibility to invasion imposed by abiotic and biotic constraints under the assumption of constant propagule pressure (Lonsdale, 1999)

predicted in the Mediterranean region except its coastline where high levels are expected, river corridors and intensively cultivated areas with irrigation. They suggest that these relatively low levels of invasion could be the result of historical factors such as the long and intensive impacts of humans in the region which have made its ecosystems resistant to some degree to current invasions. A study, (Gritti *et al.* 2006) on the vulnerability of ecosystems in five of the main islands Mediterranean basin (Mallorca, Corsica, Sardinia, Crete and Lesvos) to climate change and invasion by exotic plants showed that while the effects of climate change alone are likely to be negligible, the main factors promoting invasions is habitat disturbance. Their simulations predict that in the longer term almost all the ecosystems will be dominated by invasive aliens.

Gassó *et al.* (2009) used both species and site approaches to identify the various factors that underpin the range size of invasive plant species and make some sites more susceptible to invaders than others, so as to understand the distribution and extent of invasive plants in Spain as the basis for developing spatially explicit invasion risk protocols and scenarios of plant invasions in the Mediterranean region. Their results showed that an increasing importance of human-modified ecosystems and global warming in the Mediterranean region would facilitate the expansion of plant invaders, especially wind-dispersed species, leading to the accumulation of invasive species in some sites (i.e. invasion hot spots).

6.5 Unintentional human-assisted migration

Ornamental horticulture has been recognized as the main pathways of plant invasions worldwide (Reichard & White 2001; Dehnen-Schmutz & al. 2007; Heywood & Brunel 2009). It is estimated that 80% of current invasive alien plants in Europe were introduced as ornamental or agricultural plants (Hulme 2007). Seriously invasive plants introduced deliberately as ornamentals include Japanese knotweed (*Polygonum japonicum*), *Buddleja davidii*, *Rhododendron ponticum*, *Heracleum mantegazzianum* and a range of aquatics (*Crassula helmsii*, *Eichhornia crassipes*, *Hydrocotyle ranunculoides*, etc.). Perhaps the greatest dormant risk is the large number of plant species grown in gardens that currently survive outside their optimal climatic conditions in the reduced competition environment of cultivation. In the UK alone there are as many species in cultivation as in the wild (RHS Plant Finder 2009, Stace 1997), many are at the northern edges of their current climatic limits. Some have already shown invasive ability such as the *Carpobrotus edulis/acinaciformis* aggregate from South Africa which has invaded southern Europe through plants introduced for ornament and for stabilisation of sand dunes and the northward move of *Quercus ilex* from its native distribution to become a weed of southern coasts in the United Kingdom. Even garden *Cyclamen*, slow growing cormous plants, have shown the ability to spread throughout the UK and appear to be increasing in response to climate warming (Yesson & Culham, 2006a) while these species may be under threat of extinction within native areas of distribution.

The great range of southern Mediterranean and South African grasses that are now becoming popular garden plants may offer the greatest threat yet to the native flora of Europe as these grasses are being chosen specifically for their toughness and ability to survive greater climatic extremes. The use of green roofs and living walls (Dunnett & Kingsbury 2004; Snodgrass & Snodgrass 2006) has so far incorporated only a small number of species, often drought tolerant *Sedum* with little invasive potential, but these new growing spaces are now attracting more creative horticultural use and this has led to yet more species being introduced from other parts of the world. These species are being selected for their ability to establish from seed on substrates such as crushed concrete and other industrial waste in the harsh environment of a green roof (Hitchmough 2008). Such pre-selection for tolerance and competitiveness could result in an elite set of introductions that will spread through cities and into suburban areas along roads and pavements generating a wave of weedy but decorative invasives.

Botanic Gardens have been the source of numerous invasive species around the world and as a tool for helping botanic gardens identify potentially invasive species, the European Botanic Gardens Consortium has compiled a database of over 600 problem species which is being regularly updated[20].

[20] Sharing information and policy on potentially invasive plants in Botanic Gardens. A European Botanic Gardens Consortium project http://www.plantnetwork.org/aliens/ (accessed 12 June 2009)

The top 12 problem species for the Atlantic, Continental and Mediterranean climatic regions are given in Table 6.1:

Atlantic	Continental	Mediterranean
Fallopia japonica	*Solidago canadensis*	*Ailanthus altissima*
Heracleum mantegazzianum	*Acer negundo*	*Oxalis pes-caprae*
Elodea canadensis	*Elodea canadensis*	*Robinia pseudoacacia*
Impatiens glandulifera	*Impatiens glandulifera*	*Araujia sericifera*
Fallopia sachalinensis	*Impatiens parvifora*	*Carpobrotus edulis*
Elodea nuttallii	*Conyza canadensis*	*Conyza bonariensis*
Epilobium ciliatum	*Fallopia japonica*	*Azolla filiculoides*
Solidago canadensis	*Robinia pseudoacacia*	*Conyza canadensis*
Lemna minuta	*Ambrosia artemisiifolia*	*Elodea canadensis*
Buddleja davidii	*Heracleum mantegazzianum*	*Sporobolus indicus*
Rhododendron ponticum	*Ailanthus altissima*	*Veronica persica*
Robinia pseudoacacia	*Helianthus tuberosus*	*Acer negundo*

6.6 Codes of conduct

One of the approaches employed to try and enhance awareness and influence the behaviour of different interest-groups in horticulture, such as the horticultural industry and nursery trade, landscape architects, gardeners, park managers, with regard to the availability of invasive plant species is the preparation of voluntary codes of conduct. The Council of Europe has prepared a Code of conduct on horticulture and invasive alien plants (Heywood and Brunel 2009) and at a national level, the United Kingdom has published a Code of Practice for Horticulture aimed at preventing the spread of alien invasive species (DEFRA 2005). Other Codes or guidelines aimed specifically at botanic gardens include the German-Austrian Code of Conduct for the cultivation and management of invasive alien plants in Botanic Gardens (Kiehn 2007). However, as Dehnen-Schmutz & Touza (2008) point out, such codes or guidelines have no specific targets or time-frame and their effectiveness depends largely on how well they are promoted. One of the major obstacles to their successful implementation is the lack of readily accessible information about the actual or potentially invasive species to which they refer. Doubt has been cast on their effectiveness to date and if this perception is correct then strenuous action will need to be taken to remedy this before climatic change starts having more serious impacts.

7. PLANNED ADAPTATION: IMPLICATIONS FOR CONSERVATION STRATEGIES AND ACTION

The major biodiversity conservation challenge posed by climate and other aspects of global change is quite simply how do we manage to maintain biodiversity in a period of rapid change with a set of strategies that are essentially static and spatially confined, such as protected areas (Hagerman & Chan 2009)?

In addressing the likely consequences of climate change both mitigation and adaptation strategies are essential elements of our response but the main conservation strategies are concerned with planned adaptation. Looking at Bern Convention plant species, Natura 2000 and the Emerald Network, and European plant life in general, we need to consider the effectiveness of existing conservation approaches, consider how they may be changed or adapted to face the problems posed by climate change and also consider what novel solutions might be put forward.

The main planned adaptation options that have been proposed are to:

1. Reinforce, enhance and expand the existing protected area systems
2. Strengthen measures for biodiversity conservation outside formally protected areas
3. Ensure that there is as a wide a representation as possible of the genetic variation in the populations of target species in protected areas
4. Facilitate the possibility of gene flow through the populations of species

5. Increase the implementation of *in situ* conservation at the species level through conservation management/recovery plans
6. *Inter situs* conservation/re-introduction of species
7. Strengthen *ex situ* approaches such as seed banks, botanic gardens
8. Habitat rehabilitation

In addition, some more innovative approaches such as plant micro-reserves and human assisted migration and the adoption of a bioregional or landscape approach have been proposed.

7.1 The context

The context of plant conservation in Europe is determined by the Bern Convention, the EU Habitats Directive[21], the CBD Global Strategy for Plant Conservation (GSPC) and the European Strategy on Plant Conservation (2008–2014) (Planta Europa 2008), as well as by national policies and laws. The European Strategy for Plant Conservation (2008–2014) was adopted by the Standing Committee of the Bern Convention in November 2008. The significance of this strategy is that it is closely modelled on the 16 targets of the Global Strategy with specific European targets and activities under each of the global targets[22]. Unlike the Global Strategy, which is now under review, it takes into consideration the emerging issue of climate change. The targets are time-bound with a completion date of 2014. The most relevant targets in the context of this present report are: 4 and 5: Conserving ecological regions and important areas for plants, 7 and 8: Threatened species conservation and 10: Invasive alien species.

The use of time-bound targets in conservation is a recent development in biodiversity conservation and little attempt has been made to discuss the concept of targets in conservation or scrutinize critically the target setting process (Maltby & al. 2006). It is important to ensure that the targets are clear and unambiguous, bearing in mind the difficulties of defining biodiversity in a precise and measurable manner (Heywood 2006).

The recent report on progress between 2002 and 2008 in meeting the GSPC (CBD 2009), highlights some of the difficulties encountered with particular targets because of a lack of clarity in their initial definition and failure to establish a baseline.

7.2 Protected areas

Setting up a system of protected areas constitutes the main strategic approach to biodiversity conservation in most countries but climate change is bringing into focus our reliance on such an approach as our main tool for *in situ* conservation of biodiversity (Spalding & Chape 2008). The effectiveness of protected areas as a long-term strategy in conserving biodiversity is beginning to be called into question and several surveys have been undertaken to assess this (e.g. WWF 2004). A simple site-level tracking tool to facilitate reporting on management effectiveness of protected areas has been developed for WWF and World Bank projects (Stolten & al. 2003).

7.2.1 The situation today

In a world that is dynamic and changing, however, protected areas remain static. As they are at present constituted, protected areas are not able to buffer against broad-scale shifts in the distribution of species or ecosystems, which presents us with a serious dilemma (Lee & Jetz 2008). Protected areas as such do not migrate, even though some of their component species do, either within the area or outside it, nor can they be moved. Even assuming that viable ecological assemblages are established in the areas into which migration has taken place, they will no longer in many cases have any status of protection so that the whole legal, social, political, scientific and financial process of reserve establishment, will have to be initiated again (Heywood 2009b).

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[21] The Bern Convention and the Habitats Directive have exactly the same objectives – both are international legal instruments aimed at conserving wild flora, fauna and natural habitats. Natura 2000 and the Emerald Network are the main core areas of the Pan-European Ecological Network (PEEN)

[22] The Plant Conservation Report (CBD 2009) , a review of progress in implementing the GSPC, notes that 'While substantial progress has been reported for eight of the sixteen targets, limited progress has been made so far in the achievement of others…' .

With more than 53 000 protected areas representing c.17% of the land area (Crofts 2008), Europe has one of the most complex and diverse protected area systems in the world, corresponding to national systems on the one hand and the requirements of various international or regional agreements or conventions on the other. Examples of the latter are the Bern Convention's Emerald Network[23], the EU Natura 2000 network, the Barcelona Convention's Special Protected Areas of Mediterranean Importance and the Alpine Convention's Alpine Network of Protected Areas. There are more World Heritage and Ramsar sites and UNESCO Biosphere Reserves in Europe than in any other region.

Yet it is clear that there are still serious concerns that the present distribution of protected areas does not achieve adequate coverage of areas of biodiversity importance, both nationally and at a continental scale. In Spain, for example, based on a sample that included 2246 species of dicotyledon, 429 monocotyledons, 124 pteridophytes, 21 gymnosperms, a study used gap analysis of to determine how well existing Iberian protected areas represented plant (and vertebrate) species (Araújo & al. (2007). They made a preliminary identification of the areas that need to be added to the existing protected-area network of Spain and Portugal to achieve a more complete representation of Iberian biodiversity and calculated that 'with an optimistic assessment of representation of species in existing protected areas (designed to minimize omission errors) at least 36 additional 50 × 50 UTM cells would be necessary to guarantee full representation of selected Iberian terrestrial vertebrates and plants species. Nearly 72% of these areas are irreplaceable for the goal of full representation of species within protected areas'.

Other concerns are the effectiveness and quality of management of our exiting protected area networks and whether they are fulfilling the goals of biodiversity conservation. Many protected areas are still subject to external pressures from intensive agriculture subsidized by the EU Common Agricultural Policy and from infrastructural projects for economic development (Crofts 2008). In his review of protected areas and climate change in Europe Araújo (2009) notes that the Natura 2000 network is more vulnerable and no more effective in retaining climate conditions for Habitat Directive species than the surrounding matrix, partly due to the existence of extensive areas of farmland among the Natura sites.

The first step that should be taken is to review the effectiveness of the management of existing protected areas in biodiversity conservation (Roe & Hollands 2004), especially those of the Pan-European Network (Emerald Network and Natura 2000), to ensure that they are properly implemented and enforced, that the natural processes of ecosystem functioning are maintained and steps taken to restore them when degraded and actions taken to strengthen and consolidate the areas where necessary and an assessment made of the costs involved**.**

7.2.2 Projected impacts of climate change

The impacts of climate change on protected areas in Europe needs much more detailed work on a national basis. Various papers suggest that many protected areas will suffer moderate to substantial species loss and some protected areas may disappear altogether with catastrophic species loss but the evidence is still equivocal and is likely to remain so while there is still uncertainty as to the scale and extent of climatic and other change. For example, an assessment was undertaken by Araújo & al. (2004) of the ability of existing reserve-selection methods to secure species in a climate-change context. It used the European distributions of 1200 plant species and considering two extreme scenarios of response to climate change: no dispersal and universal dispersal. The results indicate that 6–11% of species modelled would be potentially lost from selected reserves in a 50-year period. In a study on protected area needs in a changing climate, Hannah & al. (2007) concluded that protected areas can be an important conservation strategy under a moderate climate change scenario, and that early action may be both more effective and less costly than not taking or delaying action. One of the three areas studied was Western Europe and the results suggested that protected areas remain effective in the early stages of climate change, while adding new protected areas or expanding current ones

[23] For EU Member States, Emerald network sites are those of the Natura 2000 network: Albania, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia,Georgia, Hungary, Latvia, Lithuania, "the former Yugoslav Republic of Macedonia", Malta, Moldova, Norway, Russian Federation, Slovakia, Slovenia, Iceland,Poland, Romania, Serbia and Montenegro, Turkey, and Ukraine,

would maintain species protection in future decades and centuries. For a more detailed discussion see the review by Araújo (2009).

At a national level, of the 32 priority habitats in the UK Biodiversity Action Plan, seven were assessed to be at high risk from the direct impacts of climate change, based on good to moderate evidence: montane habitats, standing waters, floodplain and grazing marsh, salt marsh, maritime cliffs and slopes, saline lagoons and open seas. Five of these are within the Coastal and Marine sector. A further 14 were assessed to be at medium risk and 11 at comparatively low risk or medium low risk. However, the evidence base was rated as 'poor' for 12 priority habitats (Mitchell *et al.* 2007) .

The challenges of adapting protected areas and their management to changing climatic conditions have been addressed by several authors (Halpin 1997; Hannah 2003; Malcolm & Markham 2000; Hannah & Salm 2003; Lovejoy 2006; McNeely 2008; United States CSSP 2008). The IUCN World Commission on Protected Areas has published a major review that deals with how to design protected areas for a changing world (Barber & al. 2004), covering issues of governance, participation and equity, capacity building and ways of evaluating effective management.

The main actions that have been proposed for protected areas are:

- Active protection and management of existing habitats
- Reducing anthropogenic stresses such as fragmentation or pollution
- Expanding the size of habitats by extending, where possible, into suitable adjacent habitats
- Extending existing protected areas into areas projected to be climatically suitable
- Ensure adequate representation by maintaining a portfolio of variants of ecosystems
- Replication through maintaining more than one example of each ecosystem
- Planning for connectivity and habitat/ecosystem/ecological networks
- Creation of new areas

Specifically for Europe, the review by Huntley (2007) in this series of reports makes a detailed series of recommendations for adaptation strategies and will not be repeated here.

7.2.3 Implications for management of protected areas

Climate change has major implications not only for protected areas but for protected area management and managers (Schliep *et al.* 2008). As Hagerman & Chan (2009) point out, protected area managers have tended to adopt minimum intervention procedures but will need to reassess their management objectives, paying attention to the maintenance of ecosystem health, the conservation needs of target species, and be prepared for more frequent and sometimes intense management interventions.

7.2.4 Representation of threatened species in protected areas

One of the principal reasons for establishing protected areas networks is to provide a secure habitat for the species that they house, especially if they are rare or threatened or of special economic or scientific importance such as crop wild relatives although designaton of protected areas alone does not guarantee protection of the natural ecosystems within their boundaries. Many conservationists advocate the role of protected areas in conserving not only ecosystems and landscapes but the diversity of species that they house. This is sometimes referred to as the coarse filter approach. However, it needs to be stressed that the setting aside of protected areas does not guarantee in any way the adequate conservation of the species it houses and for these a fine filter approach in the form of targeted species conservation measures is needed.

While it is true that protected areas may often include better quality habitats than areas outside them which may be degraded by human activities (Huntley 2007; but see also Araújo 2009)) and thus provide favourable habitats for maintaining species populations, the effective conservation of individual species also depends on an adequate sample of their genetic variability being represented in the populations included in the areas.

What we have to determine for the Bern Convention species is

- are they all adequately are represented in protected areas?
- which protected areas are likely to remain suitable for the species they currently house
- how adequate that representation is in terms of population and genetic coverage
- for which of them are management/conservation/recovery plans in place

Bern Convention Appendix 1 species (as modified in Annex 6) of EU member countries are required to be represented in Special Areas of Conservation (SACs) of the NATURA network established under the Habitats Directive and designed to 'provide rare and vulnerable animals, plants and habitats with increased protection and management'. In the case of the NATURA 2000 network, the proposed sites have to undergo a rigorous evaluation process by the national authorities for each of the species and habitats individually in relation to their specific conservation needs. The idea is that the network of sites should be adequate to ensure the long-term survival of both the habitats and species, provided appropriate conservation measures are put in place. The consultation process followed for the selection of sites have, in practice, varied considerably between Member States in accordance with their administrative systems (CEC 2003). While substantial progress has been made in implementing the NATURA 200 network, it is clear from the Habitats Directive Article 17 Reports on Implementation Measures and from perusing the species and habitats assessments on EIONET's Article 17 Webtool that there are still substantial gaps in habitats assessments and management planning and implementation, in species' population information and preparation or implementation of management or recovery plans.

Up until now, most of the effort in implementing the Habitats Directive has focused on the establishment of the Natura 2000 network. This first pillar of the directive refers to the conservation of natural habitats and of the habitats of species. The Habitats Directive however comprises a second pillar, which is related to the protection of species and a guidance document on the strict protection of animal species has been prepared in 2007 but not one for plants.

It is clear that many threatened species, whether Berne Appendix 1 species or not, are not covered by Europe's protected area systems. Even in a country such as Spain with a well developed conservation infrastructure a detailed analysis of the 586 most threatened species in the latest plant red list for Spain (Moreno 2008) shows that 75% of them have some or all of their populations in a protected natural area, mostly in National Parks. The remaining 25% have no habitat protection at all. This is not surprising in that protection of adequate populations of target plants species or assemblages of species has not been the objective in setting up most protected areas.

A general conclusion must be that more strenuous action is needed if existing statutory provisions are to be adequately implemented. In addition, it has to be asked whether these instruments are in themselves comprehensive enough to cover all Europe's threatened plant diversity at both a habitats and species level (see also Sect. 7.6.1).

7.2.5 Role of habitat networks

The concept of ecological or habitat networks is one of the most commonly proposed adaptation actions and is becoming increasingly important in both policies and practices of nature conservation throughout Europe. A detailed review of ecological networks and corridors in Europe is included in Bennett and Mulongoy (2006). The establishment of the Pan Ecological European Network (PEEN) is seen as one of the priority issues for nature conservation. Two other European networks are the Transnational Ecological Network (TEN, a cooperative project between regional governments in the United Kingdom, the Netherlands, Germany and Denmark that is focusing on wetlands and aquatic ecosystems) and the Green Belt (intended to stretch along the entire border region of the former Iron Curtain). In addition many European countries have developed or are developing ecological networks such as the Italian National Ecological Network (REN) and there are several regional networks such as the Flemish and Walloon Ecological Networks in Belgium, the Continuum Project which aims to implement an ecological network in the Alps (Kohler & al. 2008) and the Cantabrian–Pyrenees-Alps Great Mountain Corridor in France and Spain.

The concept of climate-proof ecosystem networks has been developed recently (Vos & al. 2008).

In Europe, a multi lateral initiative to establish a stronger (i.e. 'climatically robust') network of ecological areas is the Pan-European Ecological Network PEEN. The Netherlands have a similar ecological network (Ecological hoofdstructuur) that is being implemented and is intended to be a climate change-proof.

The report of the Bern Convention on climate change (Council of Europe 2008) includes the following recommendation: 'Networks of protected areas should be embedded within a high-quality landscape conservation approach to provide permeability and connectivity to assist species adjust their spatial distributions, through the provision of habitat 'stepping stones' and other tools. Protected areas alone will not be sufficient to ensure adequate protection of habitats and species. It will be critical to ensure the continued protection and appropriate management of existing protected areas which, to be effective, should need to be complemented by appropriate management and structure of the wider landscape, as otherwise many species will be unable to achieve the responses to climatic change that are essential to their long-term survival'.

7.3 Plant Micro-Reserves (PMR)

Small-scale reserves, frequently referred to as plant micro-reserves, have been established in various parts of the world to afford protection to threatened species, usually in fragmented vegetation. In the last 10–15 years, a great deal of interest has been generated by the network of plant micro-reserves established in the Valencia region in Spain (Box 7.2). Micro-reserves in the Spanish sense are small-scale protected areas, usually less than one or two hectares, and often with a high concentration of endemic, rare or threatened species. They may be considered as an option in areas where the vegetation has been subject to fragmentation and the species populations they contain similarly reduced or fragmented. Because of the small area they occupy and their frequent simplicity in legal and management terms, it may be possible for them to be established in great numbers and to complement the larger, more conventional protected areas. On the other hand their viability in the medium- to long-term must remain in question, especially in the light of global change.

Box 7.2 Spanish plant micro-reserves (From Laguna 2001 and http://microreserve.blogspot.com/)

A network of plant micro-reserves (PMR) was pioneered in Spain by Enrique Laguna of the environment agency (Conselleria de Medio Ambiente) of the regional government of Valencia, Spain and the first one was established in 1997. By the end of 2008, the Valencian Community held 273 officially protected plant micro-reserves which house populations of more than 1.625 species of vascular plants. 1,288 populations of 527 species are targeted for long-term monitoring. The sites are protected by orders of the environment agency. The management plan designates a few priority plants in each PMR, which are targeted for conservation actions (census, management projects, population reinforcement if required, etc). Only two actions are designated for all the PMRs: census of priority species, and the collection of their seeds to be transferred to the Germplasm Bank of the Botanic Garden of the University of Valencia. More than 1050 populations, belonging to 450 taxa, have been targeted for census and seed collection; however, both actions are still at the starting point for most PMR, so their implementation represents an important challenge for the next years.

Micro-reserves have also been established in others parts of Spain, notably in Menorca and the model is being introduced in some other European countries. A pilot network of microreserves in Western Crete was set up under the EU LIFE Nature 2004 programme[24] with the protection of the six threatened Cretan endemic plants (Annex II* of Habitats Directive) and of one priority habitat as its main objective. Four plant micro-reserves have been established in the area of Lefka Ori, for the *in situ* protection of *Hypericum aciferum*, *Bupleurum kakiskalae*, *Nepeta sphaciotica* and *Cephalanthera cucullata*, which are found only in very restricted areas. Other important plants also occur within these micro-reserves and are thus afforded some degree of protection as in the case of the micro-reserve of *Nepeta sphaciotica*, in an area of 4.8ha on the summit Svourichti of Lefka Ori, at 2300m altitude. 37 other endemic and threatened plant species are located there and afforded some degree of protection as well (MAICH, 2005; Fournaraki & Gotsiou 2007)). One of the species targeted was,

[24] "CRETAPLANT – A pilot network of Plant Micro-Reserves in Western Crete" (LIFE04/NAT/GR/ 000104) (http://cretaplant.biol.uoa.gr).

Phoenix theophrasti a wild relative of the date palm, at Preveli beach, listed in the Bern Convention Appendix.1

7.4 Conservation outside protected areas

National parks and other conservation reserves, which in all cover about 12-13% of the earth's surface, cannot alone ensure the survival of species and ecological communities, even without the impacts of accelerated global change. It is crucial, therefore that lands outside national reserve networks be managed in ways that allow as much biodiversity as possible to be maintained. The *in situ* conservation of biodiversity outside protected areas, where most of it occurs, is a seriously neglected aspect of biodiversity conservation and in the face of global change it must demand much further attention from countries and conservation agencies. As McNeely (2008) remarks, 'under any realistic scenario of the future, protected areas by themselves will be insufficient for actually conserving the planet's biodiversity unless the land and waters outside the protected area system are managed in ways that are consistent with the conservation objectives of protected areas'.

Formal protected area systems can be complemented by a range of indirect means whereby some degree of protection to the species they house can be provided, such as agreements to reduce the level of exploitation or to contain threats. They may be public or private initiatives and include:

1. Conservation easements both voluntary and legal, including covenants, trusts, partnerships, with or without financial or tax incentives
2. Incentive-based schemes
3. Local conservation strategies
4. Public and private collaboration for conservation

Off-site conservation areas have been employed with varying degrees of success in various parts of the world such as Australia, Brazil, China, Costa Rica, Mexico, South Africa and the USA. They include production forests, agricultural landscapes and urban landscapes, roadsides and transport corridors (Heywood 2009). In Europe, various agri-environmental policies have been adopted, the best known scheme being the setting aside of 10% of each EU farm for environmental purposes. Although set-aside was intended as a mechanism to control overproduction and although widely debated it had substantial environmental benefits for habitats, buffering watercourses and creating landscape diversity, especially in cereal farming and was especially beneficial for insects and birds (Kleijn & Sutherland 2003; Van Buskirk & Will 2004). A study of the impact of climate change on the delivery of biodiversity through agri-environment schemes (Finch-Savage *et al.* 2007) suggests that the possibly biggest impacts on biodiversity are likely to be due to extreme events and indirect effects associated with agricultural change.

It is not known how such schemes affect the working of the Bern Convention but it seems logical that they should be explored further as part of a bioregional or landscape approach to conservation planning that will be needed as a response to global change.

7.5 Species conservation

Species conservation may be undertaken both *in situ* and *ex situ.*

7.5.1 In situ conservation

In situ conservation of species is a task that has proved difficult to implement (Heywood & Dulloo 2005; Heywood 2005) even though it is explicitly mandated by the Convention on Biological Diversity in Article 8 **'…***the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties***'.** Specifically, it is also addressed by the CBD's Global Strategy for Plant Conservation by both targets vii, 60% of the world's threatened species conserved, *in situ* and viii, 10% of threatened plant species included in recovery and restoration plans, although progress in implementing these targets has been very limited, partly because of a failure to clarify just what actions were required to meet them. At a European level, the European Strategy for Plant Conservation (endorsed by the Bern Convention Standing Committee), target 7.1 is: *60% Of European conservation priority plant and fungal species … conserved in situ by 2014…*

7.5.2 Bern Convention context

The two principal and complementary components in both the Habitats Directive and the Bern Convention are conservation of listed habitats and species. While progress in the first element has been substantial, implementation of species conservation has been disappointing. It is in fact extraordinarily difficult to obtain accurate and up to date information on how far recovery, conservation and management plans for Bern Convention species have been implemented. The reports on progress by the countries on Recovery, conservation and management plans for Bern Convention species as reported in Strasbourg, 14 October 2004 T-PVS (2004) 11 are incomplete and uneven. It is clear from these reports and from the information recorded in EIONET's Article 17 Webtool, as noted above, that a considerable number of Bern Convention/Habitats Directive species are not the subject of management or recovery plans and for many others the plans are only in preparation rather than being implemented.

Appendix 1 of the Bern Convention is a list of 'Strictly Protected Flora Species' and has been subject to periodic amendments. It was revised in Resolution No. 6 (1998) of the Convention which identified a list of species 'requiring specific habitat conservation measures'. These species were selected largely to be consistent with Annex II of the Habitats Directive, that is species of 'community interest whose conservation requires the designation of special areas of conservation'. Thus the main criteria used were related to their threatened status. The specific habitat conservation measures required were, fundamentally, designation of important sites into the Emerald network to include these species (E. Fernández.Galiano pers. comm. to vhh).

In its Recommendation No. 30 (1991) on conservation of species in Appendix I to the convention (adopted by the Standing Committee on 6 December 1991) paragraph 4. reads: *as a matter of urgency, formulate and implement conservation or recovery plans for endangered and, if necessary, vulnerable species listed in Appendix I, giving priority to in situ conservation action.* In Recommendation No. 40 (1993) on the elaboration of conservation or recovery plans for species in Appendix I to the convention (adopted by the Standing Committee on 3 December 1993) it is recommended that the Parties:

1. formulate and implement conservation or recovery plans for some endangered or vulnerable endemic species listed in Appendix I to the Convention for which the plans are found useful by the Parties;

2. formulate and implement conservation or recovery plans for some Appendix I species which are endangered or vulnerable in all or part of their European range, such as those in the appendix to this recommendation, which have been identified as requiring conservation or recovery plans in the territory of several Contracting Parties;

3. inform the Standing Committee on the progress of the above recommended plans, as well as of other similar plans for other plant species.

An Appendix to the recommendation listed 13 examples of Appendix I species identified as requiring conservation or recovery plans:

Botrychium simplex
Ligularia sibirica
Aldrovanda vesiculosa L.
Coleanthus subtilis
Najas flexilis
Cypripedium calceolus
Liparis loeselii
Pulsatilla patens
Thesium ebracteatum
Saxifraga hirculus
Trapa natans
Angelica palustris
Buxbaumia viridis

A report on the implementation of the Bern Convention in Spain (CoE 2006) notes that as regards critically endangered species, the 1999 Spanish Strategy for the Conservation and Sustainable Use of

Biodiversity had 149 species on the national list, but only 6 recovery plans had been approved and 14 were under preparation.

The subsequent implementation of these recommendations has been patchy and in view of the imminent threats from climate change, it is recommended that the countries concerned should review the state of recovery planning for their listed species and formulate management or recovery plans for those that are not so far covered. Unless such action is taken now to ensure the survival of these threatened species, they risk becoming extinct or diminished thus pre-empting the option to take additional action in the future in the face of accelerated climate change.

7.5.3 Reintroduction, inter situs conservation and human-assisted migration of species

In addition to the reinforcement (augmentation) of species' populations as part of a recovery programme, various degrees of reintroduction of species into habitats have been employed for threatened plant species in Europe and are likely to become more widely employed as the numbers of species at risk of extinction through climate change increases. Reintroduction is 'the deliberate establishment of individuals of a species into an area and/or habitat where it has become extirpated with the specific aim of establishing a viable self-sustaining population for conservation purposes' (Maunder 1992) . It may involve the establishment of an extirpated species into a relatively intact habitat or it can be part of the restoration of a degraded habitat. It is generally accepted that plants should only be reintroduced into sites where the species was once known to occur, or into typical habitats within the documented range of the species.

Although it is tempting to advocate a more widespread use of plant reintroduction in Europe in response to climate change, like all deliberate movement of individuals it is an experiment and must be subject to careful assessment and monitoring if meaningful results are to be obtained (Primack 1998) and the demographic viability of translocated populations properly evaluated (Moritz 1999). It is also a costly and laborious procedure and with little guarantee of success.

No overall evaluation of the effectiveness of plant reintroductions in Europe (or indeed elsewhere) has been undertaken and few scientifically documented reintroductions of plant species have been attempted (Moritz 1999; Leinert 2004), many of them being undertaken by conservation bodies, botanic gardens and amateurs without adequate scientific backup, follow-through and monitoring. It is difficult to identify any successful reintroduction experiments (cf. Pavlik 1994). An example of an apparently successful reintroduction is that of *Filago gallica* in Britain (Rich *et al.* 1999) although in small numbers at a single site.

An EU project TRANSPLANT[25] had as its aim, the determination of the extinction risks and the re-introduction of plant species in a fragmented Europe. One of the difficulties of plant reintroduction at a European level is the paucity of information on case studies and best practice and what experience is available is often not published in the scientific journals but in the grey literature (Godefroid & Vanderborght 2009). A search made under the auspices of ENSCONET revealed that using the ISI Web of Science database, only 12 publications relating to reintroduction experiments in Europe between 1955 and 2009, while a search of the grey literature showed that reintroduction projects exist for at least 234 species in 18 European countries (Godefroid & Vanderborght 2009 and Godefroid per.comm. June 2009). A global online register of plant reintroductions is being prepared by the US Center For Plant Conservation and it planning to review reintroductions, their successes and failures, promises and deliveries. At a national level, the Italian Botanical Society has launched a project to document plant reintroduction and recovery projects in Italy[26] with a view to compiling a national database. A survey revealed that reintroduction had been attempted for 50 species (Rossi & Bonomi 2007)

The term *inter situs*[27] conservation has been applied to the reintroduction of species to locations outside the current range but within the known recent past range of the species[28] (Burney and Burney

[25] TRANSPLANT - Extinction risks and the re-introduction of plant species in a fragmented Europe (FP5 - Sustainable development, global change and ecosystems) (2000-03-01 - 2004-02-28) http://www.euprojekt.su.se/index.php/kb_4/io_1315/io.html

[26] www.societabotanicaitaliana.it Grupo di lavoro, Conservazione della Natura

[27] Usually referred to, incorrectly and ungrammatically, as *inter situ.*

2009). It contrasts with 'assisted migration' discussed below. It has been practised with apparent success to save rare Hawaiian plants but has not yet been applied to European species. It is a procedure which involves considerable risks.

7.6 Human-assisted migration/colonization

In recent years, increasing interest is being shown in human-aided translocation of species' populations as a means of responding to the problem that some species may not be able to track changing climatic conditions quickly enough. Also known as managed relocation (Richardson *et al.* 2009), human-assisted migration (McLachlan & al. 2007) or assisted colonization[29] (Hunter 2007; Hoegh-Guldberg 2008) and assisted translocation, it deals with the introduction of species (or communities) to into an areas where they have not existed in recent history i.e. not at present within their 'native' ranges. It is being proposed for situations where the rate of change, the existence of obstacles or barriers or the lack of continuous suitable habitat is considered likely to prevent natural migration. It is a complex and potentially costly venture and needs to be subject to careful cost-benefit analysis and perhaps used only in exceptional circumstances.

Moving species into new environments is, as McLachlan & al. (2007) say, a contentious issue and may involve considerable risks (see also Mueller & Hellmann 2008). Although the credibility of assisted migration has received support from various organizations and individual scientists (Dixon and Sharrock, 2009), others such as Ricciardi and Simberloff (2009) argue strongly against it, mainly on the grounds that we do not yet have sufficient understanding of the impacts of introducing species to new habitats to be able to make informed decisions to allow us to adopt this approach (see also Campbell 2008). As Hagerman and Chan (2009) point out, assisted colonization as an approach is 'at odds with current reserve management in which substantial efforts are directed at keeping non-native species out. It also carries with it substantial risks because introduced species may become invasive and displace other valued ecosystem elements'. On the other hand, Richardson *et al.* (2009) believe that its importance as a conservation strategy will increase as global change takes hold and believe that it should not be considered a priori as a last resort approach but as one of a portfolio of options. They note that we may increasingly have to make decisions in the absence of full information and argue that the numerous interacting and value-laden considerations involved in assisted migration demand a more inclusive strategy for its evaluation. They propose a 'heuristic tool that incorporates both ecological and social criteria in a multidimensional decision-making framework'.

Human-assisted migration is then a complex issue involving not just scientific, technical and economic but sociological and ethical considerations. It requires a sound and well thought out policy framework before it is widely undertaken as a management response to global change (Hoegh-Guldberg 2008; Richardson *et al.* 2009). In Europe, it may, however, be worth considering for Bern Appendix 1 species of particular importance or concern but only after very careful and detailed assessment of the potential risks and consequences. Certainly, if it is rejected out of hand, some species could become extinct. Yesson & Culham (2006a) have proposed this solution to the long term survival of a range of *Cyclamen* species based on current *ex situ* behaviour of this genus in garden settings.

As mentioned above (Section 6), gardens can be unintentional agents of assisted migration. Van der Veken *et al.* (2008) compared the native ranges of 357 native European plant species with their commercial ranges, based on data from the holdings of 246 plant nurseries throughout Europe and found that in 73% of native species, the commercial northern range limits exceeded natural northern range limits, with a mean difference of ~ 1000 km. As they comment 'With migration rates of ~ 0.1–5 km per year required for geographic ranges to track climate change over the next century, we expect nurseries and gardens to provide a substantial head start on such migration for many native plants. While conservation biologists actively debate whether we should intentionally provide "assisted migration", it is clear that we have already done so for a large number of species'.

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[28] This usage differs from that of Blixt (1994) who applies it to the maintenance of domesticates in farmers' fields, more commonly referred to as on-farm conservation.

[29] Hunter uses the term *assisted colonization* in contrast to *assisted migration* 'because many animal ecologists reserve the word *migration* for the seasonal, round-trip movements of animals […] and because the real goal of translocation goes beyond assisting dispersal to assuring successful colonization, a step that will often require extended husbandry'.

7.7 *Ex situ* complementarity

After a period in which *ex situ* conservation has been downplayed by the conservation community (except for agrobiodiversity where it is still the main conservation strategy) *ex situ* conservation is now widely accepted as an increasingly necessary complement to *in situ* forms of conservation (IUCN 2002; BGCI 2000), especially protected areas (e.g. Abanades García & al. 2007). The main forms of *ex situ* conservation for plants are in seed banks, or field genebanks and living collections in botanic gardens and arboreta The main aims of *ex situ* conservation are given in Box 7.3..

Box 7.3 Goals of *ex situ* management (from IUCN 2002)

Those responsible for managing *ex situ* plant and animal populations and facilities will use all resources and means at their disposal to maximise the conservation and utilitarian values of these populations, including:

1) increasing public and political awareness and understanding of important conservation issues and the significance of extinction;

2) co-ordinated genetic and demographic population management of threatened taxa;

3) re-introduction and support to wild populations;

4) habitat restoration and management;

5) long-term gene and biomaterial banking;

6) institutional strengthening and professional capacity building;

7) appropriate benefit sharing;

8) research on biological and ecological questions relevant to in situ conservation;

and

9) fundraising to support all of the above.

7.7.1 Seedbanks

A number of European botanic gardens hold significant seed banks such as that at the Jardín Botánico de Córdoba, Spain[30] which is the Germplasm Bank of the Environmental Agency of Andalucía (Banco de Germoplasma Vegetal Andaluz de la Consejería andaluza de Medio Ambiente) (Hernández Bermejo 2007) and stores more than 7,000 accessions or propagules, mainly seeds, of more than 1500 different species of Andalusian plants and about 500 other Iberian endemic species. The Millennium Seed Bank of the Royal Botanic Gardens Kew at Wakehurst Place (UK)[31] is the world's largest seed bank for wild plants. It aims to collect and conserve 10% of the world's seed-bearing flora, principally from arid zones by 2010 and already holds seed of many European species including virtually all UK native seed plant species.

Europe is very fortunate having a well organized network for the *ex situ* conservation of seeds of plant species – ENSCONET (The European Native Seed Conservation Network[32]) involving 19 institutes from 12 European countries. For the west Mediterranean, GENMEDOC, provides an inter-regional network of seedbanks[33]. In addition some national *ex situ* networks have been created, such as REDBAG (Red Española de bancos de germoplasma de plantas silvestres), the Spanish network of germplasm banks of wild plant species and RIBES (Rete Italiana Bache dei Germoplasma per la

[30] It is in fact the Germplasm Bank of the Environmental Agency of Andalucía (Banco de Germoplasma Vegetal Andaluz de la Consejería andaluza de Medio Ambiente)
[31] Millennium Seed Bank Project (MSBP) http://www.kew.org/msbp/index.htm
[32] http://www.ensconet.eu/
[33] http://www.genmedoc.org/eng/progetto/presentazione.htm

coservazione ex situ della flora Spontanea Italiana)[34], the Italian network of seed banks for *ex situ* conservation of wild plant species.

ENSCONET has developed a database of plants in seedbank collections in participating institutions. Its database now includes records for 39,704 accessions, relating to over 9,000 species, which are stored in 27 institutions across Europe. A group of institutions (covering five of Europe's six bio-geographical regions) led by the Royal Botanic Gardens Kew established a network to co-ordinate and enhance their activities under the EU's 6th Research Framework Programme.

In addition to seedbanks for wild species, the European Cooperative Programme for Plant Genetic Resources (ECP/GR) is a cooperative long term programme for the conservation of plant genetic resources in Europe, focusing on plants for food and agriculture (but including crop wild relatives). It has proposed a Strategic Framework for the Implementation of a European Genebank Integrated System (AEGIS) (ECPGR 2009). It does not specifically include (nor for that matter exclude!) botanic garden seed banks and it seems logical that we should explore how far existing European agricultural and horticultural genebanks can increase their involvement in the conservation of wild species (already many contain accessions of crop wild relatives) and that botanic gardens should work more closely with the plant genetic resources sector (Heywood 2009).

7.7.2 Botanic garden living collections

Botanic gardens are beginning to play an important role in the conservation of European plants and this is likely to increase when developing strategies for adopting to climate change. For its size, Europe has a disproportionate number of botanic gardens and arboreta (c. 800 out of a global total of 2400 plus) and several new ones have been created in the past ten years (but see below) . European botanic gardens have formed the European Botanic Gardens Consortium which consists of representatives of all EU member countries, with Croatia, Iceland, Norway and Switzerland as observers. The Consortium has published an *Action Plan for Botanic Gardens in the European Union* (Cheney & al. 2000).

Botanic garden *ex situ* collections may be used in a variety of ways relating to conservation (Maunder *et al.*, 2004). They may be used to study the reproductive biology and growth requirements of species to be used in population reinforcement as well as providing material as part of species recovery programmes or reintroduction experiments as well as in habitat restoration which will be increasingly required as a response to climate change. The challenges and the costs of maintaining living collections of plants as opposed to seeds are substantial so that their value for long-term conservation is limited.

The BGCI's consolidated list of European threatened species (BGCI 2009) was screened against BGCI's database of plants in cultivation in botanic gardens (PlantSearch) and ENSCONET's (European Native Seed Conservation Network) database of plants conserved in European seed banks. The analysis showed that 304 taxa listed on the Bern Convention appear to be included in botanic garden collections. 62 of these are only in one collection. An earlier survey of the representation of Bern Convention species in European botanic gardens revealed that of 119 European botanic gardens in 29 European countries, 105 were cultivating 308 of the 573 threatened plant species listed by the Convention (Maunder & al. 2001). The survey also identified 25 botanic gardens in 14 countries undertaking 51 conservation projects focused on 27 Bern listed species. It points out however that most of the species were represented by only small numbers of accessions and only a minority were of known wild origin. This and other factors, such as poor documentation, reduces their value considerably for conservation use (Laliberté 1997; Heywood 1999; Schoen & Brown 2001; Heywood 2009). The longevity of plants in cultivation is another limiting factor: short-lived species are difficult to maintain and will need regular replacement, a process not without risks. Other risks that have to be minimised in maintaining botanic garden collections with a view to maintaining the genetic integrity and viability of the material are loss of genetic diversity, artificial selection, pathogen transfer and hybridisation.

Even the long-term sustainability of the botanic garden has to be taken into account: as the IUCN (2002) *ex situ* guidelines note, 'Consideration must be given to institutional viability before embarking

[34] Rossi *et al.* (2005)

on a long term *ex situ* project'. Unfortunately, a number of closures of European botanic gardens or downgrading of their scientific management has occurred in recent years.

Urgent action needs to be taken to collect and store accessions of the majority of Bern Convention of species that are not at present covered by such collections, either as living collections or as seed, and to enhance the quality of sampling of those that already exist.

7.7.3 Conservation collections in arboreta

Many arboreta across Europe maintain large living collections of trees and shrubs in their arboreta. Often these are in the form of large population samples and therefore of significant conservation value and can be a source of material for habitat rehabilitation, population reinforcement or recovery of threatened species and other conservation uses, especially in a period of accelerated climate change.

7.7.4 Risks of ex situ living collections becoming a source of invasives

As discussed above (Sect. 6), botanic gardens have in the past been a source of invasive species and so in maintaining *ex situ* collections, botanic gardens should take the necessary precautions to avoid future escapes. One of the IUCN Guidelines for the management of *ex situ* populations reads 'All ex situ populations should be managed so as to reduce the risk of invasive escape from propagation, display and research facilities. Taxa should be assessed as to their invasive potential and appropriate controls taken to avoid escape and subsequent naturalisation'. The St Louis Voluntary Codes of Conduct which were developed following a workshop on 'Linking ecology and horticulture to prevent plant invasions' held in 2001 at Missouri Botanical Garden includes a Code of Conduct for Botanic Gardens and Arboreta (2002)[35] which has been widely adopted by US botanic gardens. At the EuroGardV congress held in Helsinki in June 2009, a recommendation was made to prepare a similar code for European botanic gardens.

7.8 Implementation

Most of the adaptation strategies noted above will require considerable financial and human investment but it is not at all obvious that our present structures or funding policies are adequate for present needs let alone the additional demands that responding to the effects of climate change on plant diversity will make. This is now explicitly recognized by the EU and is exemplified by the almost certain failure to meet its Millennium goals. The economics of conservation are beginning to be understood but much more documentation is needed on the cost of different conservation actions. As Heywood (2009b) notes, 'most biodiversity strategies and plans are uncosted, as if conservation existed in a cost-free environment, and what is more, most expenditure by conservation agencies does not track closely conservation priorities or guidelines (Halpern & al. 2006)'. Our knowledge of the cost implications of different conservation actions are very sketchy: as a major European Commission report, *The Economics of ecosystems and biodiversity* (European Commission 2008) notes, 'the figures available so far apply to small bits of nature here and there'. Mention has already been made of the high cost of conserving *Abies nebrodensis* but perhaps the most expensive European plant species in terms of conservation costs is the Lake Constance forget-me-not (*Myosotis rehsteineri*), which is restricted to the banks of Lake Constance (Austria, Germany, and Switzerland). Protecting its habitat in Bregenz, Austria was the subject of a LIFE-Nature project with a total budget of : € 2,040,000.00 of which Life's Contribution was €1,020,000.00! Clearly such a scale of expenditure cannot be applied today to many species facing similar degrees of threat. When we consider the increase in the number of threatened species that will be caused by climate change and the costs of recovery programmes, not to mention the strengthening and rehabilitation of protected areas, techniques such as assisted migration that have been proposed and the control or eradication of invasive alien species, the level of expenditure required would appear to be prohibitive in the context of the current financial priority given to biodiversity conservation.

Another area that is seldom addressed is whether the necessary institutional structures to carry out conservation activities exist on the scale needed. Apart from the staff involved in managing and

[35] www.centerforplantconservation.org/invasives/Download%20PDF/bga.pdf

running protected area systems, the number of dedicated conservation bodies with adequate capacity and the trained staff needed to undertake practical conservation actions in Europe is very limited. What is more, we are witnessing today a closure of departments of botany in several European universities and of botanic gardens and herbaria. This will exacerbate the current shortage of suitably qualified personnel and will increase our dependence on amateurs (where they exist!). We are beginning to face a situation where academic conservation biology is flourishing but without what have been termed the 'muddy boots practitioners' needed to carry out the necessary practical work in the field.

8. CONCLUSIONS AND RECOMMENDATIONS

All the available evidence points to the high probability that plant diversity in Europe, both at the landscape and ecosystem level and at the species and population level will be severely impacted by climate change over the course of this century, interacting with other forms of global change such as population growth and movement and changes in disturbance regimes. The impacts will not be uniform, with some regions experiencing moderate changes and turnover of species, while others may expect serious disruption of existing ecosystems and their replacement with novel assemblages of species and the loss of considerable numbers of currently rare and endangered species in specialized habitats, such as high mountains. Many species that are not currently threatened or on national Red Lists may be put at risk by climate change while others will be at risk of extinction through lack of suitable niches into which to migrate. While we have developed increasingly sophisticated tools and modelling procedures, very considerable uncertainty remains about species migrations and habitat change at the local scale. It is very likely that there will be a substantial rise in the number of invasive species with serious effects on particular habitats.

While recognizing that the Bern Convention, the Habitats Directive and individual countries have made major progress in determining which species required priority action through habitat conservation and the creation of ecological networks, implementation is not yet complete, especially in terms of area management and species-level conservation. Therefore a major effort is needed to enhance conservation actions at all levels so that we can face the effects of climate change from a more secure base.

Given that baseline data are still far from complete, for example on threatened species, identity and extent of invasions, the number of species for which conservation/management/recovery plans have been implemented, it is difficult to determine appropriate targets for action.

We need to keep the effectiveness of the Natura 2000 network and the threat status of listed species under constant review as climate change takes hold, through a major expansion of monitoring systems.

RECOMMENDATIONS

General

1. A reassessment of conservation policy should be undertaken. This should cover the effectiveness of current methods and consider new approaches, both for protected areas and for species and the balance between these efforts. The risk of devoting too much of our energies and efforts on debating methodologies and models at the expense of practical conservation action must be avoided.
2. The cost implications of conservation action and strategies should be examined and recommendations made for reviewing biodiversity budgets at a national and regional level.

Baseline studies

3. A comprehensive checklist of the European flora needs to be completed, using the Euro+Med database and all other available resources.
4. The various attempts (Alterra, BGCI, EEA, this report) to synthesise the information on threatened species should be coordinated and consolidated into an agreed list/database.
5. The likely impacts of climate change should be incorporated into the criteria for assessing threatened status of species in national Red Books or Lists and the current status of Bern/Habitats Directive (and all other European plant species) reassessed.
6. The Bern Convention Standing Committee may wish to review the aims and content of the current list of Appendix I species in the light of the greatly enhanced knowledge at national level of the threatened status of plant species and the likelihood of the impacts of climate change.

Predicting the impacts of climate change

7. Bioclimatic modelling should be applied at least to all Bern Convention listed species and countries and the information obtained from published modelling studies should be consolidated so that the results can be easily searched on a species by species basis.
8. Bioclimatic modelling should be supplemented by the application of other criteria for identifying taxa vulnerable to climate change

Protected Areas

9. Efforts should be focussed on ensuring that existing protected areas are adequately managed and monitored so that they are in as healthy a state as possible before climatic and other change intensifies.
10. A more flexible approach to protected areas should be adopted and steps taken to expand and duplicate them where possible and feasible, and incorporate mosaics, corridors, habitat networks and connectivity into reserve planning.
11. Conservation outside protected areas should be explored as a matter of urgency and proposals made for a considerable expansion of off-site arrangements such as easements, set-aside, incentive-based schemes, local conservation strategies and public and private collaboration for conservation
12. The effectiveness and sustainability of Plant Micro-reserves (PMR) over the medium to long term should be assessed

In situ species conservation

13. An urgent review should be undertaken of the *in situ* conservation needs of all threatened European species, not just those listed in the Bern Convention/ Habitats Directive
14. A conservation statement should be prepared for all threatened species and steps should be taken to accelerate the preparation and implementation of species action, management or recovery plans as appropriate.
15. Countries should review the state of recovery planning for their listed species and formulate management or recovery plans for those that are not so far covered.
16. Management interventions should be considered to facilitate species dispersal into suitable areas e.g. cliff and rupicolous plants (Farris & al. 2009)

Inter situs conservation and human-assisted migration

17. The need for *inter situs* and human assisted translocation of species that are threatened with extinction and not likely to survive in the face of climate change should be assessed and a list of candidate species prepared.

Ex situ species conservation

18. The importance of maintaining adequately sampled *ex situ* collections as seed or living collections for a range of conservation purposes should be recognized and steps taken to strengthen and improve the coverage and quality of existing seed banks and botanic garden collections.

19. Urgent action needs to be taken to collect and store accessions of the majority of Bern Convention of species that are not at present covered by such collections, either as living collections or as seed, and to enhance the quality of sampling of those that already exist.

Invasive species

20. Given that horticulture is identified as the main pathway for invasion, the Bern Convention *Code of Conduct on Horticulture and Invasive Alien Species* should be widely adopted by the horticultural trade and industry and the European Botanic Gardens Consortium should be encouraged to prepare a similar Code of Conduct for botanic gardens in Europe.

21. Strenuous efforts should be made to prevent the introduction and establishment of new invasives, through understanding vectors and pathways, risk assessment risk analysis, horizon scanning for potential new invasives, early warning systems, codes of conduct and control strategies

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ANNEX 1: Consolidated list of Bern Convention listed species showing their current IUCN Red List status, their Red List assessment according to Buord & Lesoëuf (2006), availability of a recovery plan and an indication of the number of distribution points available for niche modelling.

Species	No. of georeferenced records on GBIF (accessed 16th June 2009)	Bern Convention Annexe 1 - 1979	IUCN Redlist 2008 Status	Redlist categorization	Buord & Lesoeuf (2006)	B&L Redlist assessment	B&L Redlist categorisation	B&L review	B & L, Recovery Program
Abies nebrodensis	1	1	CR	D	1	CR	D	2006	3
Achillea alexandri-regis	0				1	CR	B1 + 2c	2006	0
Achillea glaberrima	0				1	CR	B1+2ab	2006	2
Achillea horanszky	0				1	CR	D	2006	1
Achillea spinosa	0				1	EX		2006	0
Achillea thracica	0	1							
Aconitum corsicum	0	1							
Aconitum flerovii	0	1							
Aconitum lasiocarpum	3	1							
Adenocarpus gibbsianus	10				1	CR	A4acd	2006	0
Adenophora taurica	1				1	CR	A2,B1,2a	2004	0
Adonis cyllenea	5	1							
Adonis distorta	4	1							
Adonis transylvanica	0				1	CR	B1+2ab(i,ii,iii,iv,v)	2006	0
Aegilops fragilis	0				1	CR	E	2006	1
Aethionema retsina	7				1	CR	B1ab (III,V) + 2ab (III,V)	2004	1
Agrimonia pilosa	223								
Agrostis barceloi	2				1	CR	B1ab (III,V) + 2ab (III,V) ; C2a (II)D	2006	1
Alchemilla cleistophylla	3				1	CR	B1+2c	2006	0
Alchemilla fontqueri	1				1	CR	C2a (I,II)D	2006	0
Alchemilla kerneri	3				1	CR	A1c	2006	0
Aldrovanda vesiculosa	87	1							
Alisma wahlenbergii	10	1							
Alkanna pinardii	0	1							

Alkanna sartoriana	0				1	CR	B1+2c	2006	0
Allium calamarophilon	0				1	CR	C2b ; D	2006	0
Allium corsicum	0				1	CR	A2,B1,2a,b(i,ii,iii,iv,v)	2004	1
Allium grosii	3	1							
Allium regelianum	0	1							
Allium rhodiacum	0				1	CR	B1+2c, D	2006	1
Allium ritsii	0				1	CR	B1+2c	2006	0
Allium rouyi	11				1	CR	B1ab(2,4)+2ab(2,4)	2006	1
Allium singulifolium	0				1	EW		2006	4
Allium vuralii	2	1							
Althaea kragujevacensis	0				1	EX		2006	0
Althaea vranjensis	0				1	EX		2006	0
Alyssum akamasicum	0	1							
Alyssum borzaeanum	0	1							
Alyssum montanum subsp. *pluscanescens*	0				1	CR		2006	1
Alyssum nebrodense subsp. *tenuicaule*	0				1	CR	B1+2c,	2006	0
Alyssum pyrenaicum	2	1							
Anacyclus alboranensis	0				1	CR	B1ab(iii),c(ii,iv)+2ab(iii),c(ii,iv)	2006	1
Anacyclus latealatus	0	1							
Anchusa capellii	0				1	CR	B1+2c	2006	1
Anchusa crispa	25	1	CR	B1ab(iv)c(iv)+2ab(iv)c(iv)	1	CR	B1ab(IV) c(IV) + 2an (IV) c (IV)	2006	1
Anchusa formosa	0				1	CR	B1+2c ; C2b	2006	1
Anchusa littorea	0				1	EX		2006	0
Anchusa macedonica	13				1	CR	C1a	2006	0
Androcymbium europaeum	9	1							
Androcymbium rechingeri	0	1			1	CR	A1c	2006	2
Androsace cylindrica	30	1							
Androsace mathildae	4	1							
Androsace pyrenaica	200	1							
Androsace rioxana	5				1	CR	B1, 2a	2006	0
Andryala crithmifolia	0				1	CR	B1,2ab (i,ii,v))		
Andryala levitomentosa	0	1			1	CR	B1, 2a	2006	0

Anemone uralensis	0	1							
Angelica heterocarpa	60	1							
Angelica palustris	70	1							
Anthemis argyrophylla	0				1	CR		2006	0
Anthemis asperula	3				1	CR	A1a, B1+2cd	2004	0
Anthemis chrysantha subsp. *jimenezii*	0				1	CR	B1b(iii,iv)+c(iv)+2b(iii,iv) C(iv)	2006	1
Anthemis glaberrima	2	1	CR	B1ab(ii,v)+2ab(ii,v)	1	CR	B1 (II,V) + 2ab (II,V)	2006	1
Anthemis halophila	2	1							
Anthemis ismelia	0				1	CR	B1+2c, D	2006	1
Anthemis trotzkiana	0	1							
Anthyllis hystrix	4	1							
Anthyllis lemanniana	2				1	CR	B1+2c (i,ii,iii,iv);D		
Antirrhinum charidemi	29	1							
Aphanes lusitanica	0				1	EX		2006	0
Apium bermejoi	2	1	CR	B1ab(v)c(iv)+2ab(v)c(iv); C2a(i); D	1	CR	B1ab (V) ; C (IV) + 2ab (V) ; C (IV) C2a(I) ; D	2006	1
Apium graveolens subsp. *butronensis*	0				1	CR	B1ab(3)+2ab(3)	2006	0
Apium repens	776	1							
Aquilegia barbaricina	1				1	CR	D	2006	0
Aquilegia bertolonii	152	1							
Aquilegia kitaibelii	1	1							
Aquilegia nuragica	0				1	CR	D	2006	0
Aquilegia ottonis subsp. *taygetea*	0	1			1	CR	D	2006	0
Aquilegia pyrenaica subsp. *cazorlensis*	0	1							
Aquilegia vulgaris subsp. *paui*	0				1	CR	B1ab(V)+2ab(V) ; C2a(I), D	2004	0
Arabis kennedyae	1	1	CR	B1ab(iii)c(iv)+2ab(iii)c(iv); C2a(i)	1	CR	B1ab (III), C (IV) + 2ab (III) ; C (IV), C2a (I)	2006	1
Arabis margaritae	1				1	CR	B1ab(III,V)+2ab(III,V)	2006	1
Arabis sadina	2								
Arctagrostis latifolia	868								
Arctophila fulva	359								
Arenaria bolosii	1				1	CR	B1ab (III) + 2ab (III)	2006	1
Arenaria ciliata subsp. *pseudofrigida*	0								

Arenaria gothica var. fugax	0				1	CR	B1ab (III) + 2ab (III)	2006	1
Arenaria humifusa	148								
Arenaria leucadia	0				1	CR	B1+2c	2006	0
Arenaria nevadensis	4	1	CR	B1ac(iii,iv)+2ac(iii,iv)	1	CR	B1ac (III,IV) + 2ac(III,IV)	2006	2
Arenaria phitosiana	1				1	CR	C2b	2006	0
Arenaria provincialis	6	1							
Aristolochia merxmuelleri	0				1	CR		2006	0
Aristolochia samsunensis	0	1							
Armeria alpina var. purpurea	0				1	CR	B1+2c(i,ii,iii,iv) ; D	2006	1
Armeria arcuata	0				1	EX		2006	
Armeria belgenciensis	3				1	CR	D	2004	1
Armeria berlengensis	2								
Armeria helodes	0				1	CR	A1ac;B1+2a	2006	1
Armeria maritima subsp. *azorica*	0				1	CR		2006	0
Armeria maritima subsp. *barcensis*					1	CR		2006	1
Armeria merinoi	5				1	CR	B1ab(III)+2ab(III)	2006	1
Armeria neglecta	0				1	EX		2006	0
Armeria pseudarmeria	0	1							
Armeria rouyana	5	1							
Armeria soleirolii	3	1							
Armeria velutina	5	1							
Armoracia macrocarpa	3	1							
Artemisia campestris subsp. *bottnica*	0								
Artemisia granatensis	12	1			1	CR	A2ad ; B1ab(IV,V)	2006	1
Artemisia insipida	0	1							
Artemisia laciniata	37	1							
Artemisia molinieri	3				1	CR	A2;B1,B2c(iii,iv)	2006	2
Artemisia oelandica	94								
Artemisia pancicii	10	1							
Arum purpureospathum	0	1							
Asparagus lycaonicus	2	1							
Asperula borbasiana	0				1	CR		2006	0
Asperula crassula	0				1	CR	B1 + 2c	2006	0

Asperula samia	0		1	CR	B1 + 2c	2006	0
Asperula staliana subsp. *diomedea*	0		1	CR	B2c+3c	2006	0
Asphodelus bento-rainhae	2	1					
Asplenium hemionitis	16	1					
Asplenium jahandiezii	41	1					
Aster pyrenaeus	441	1					
Aster sibiricus	278	1					
Aster sorrentinii	2						
Astragalus agrantioii	0		1	CR	B1+2c	2006	0
Astragalus aitosensis	0	1					
Astragalus algarbiensis	0	1					
Astragalus aquilanus	1	1					
Astragalus cavanillesii	2		1	CR	B2ab (V) ; (I)	2006	0
Astragalus centralpinus	18	1					
Astragalus devesae	3		1	CR	B2ab (III) ; C2a (II)	2006	0
Astragalus drupaceus	2		1	CR	C2a	2006	1
Astragalus gines-lopezii	6		1	CR	B2c+3c	2006	0
Astragalus idaeus	1		1	CR		2006	0
Astragalus kungurensis	0	1					
Astragalus macrocarpus subsp. *lefkarensis*	0	1	1	CR	B2ab (V)	2004	1
Astragalus maritimus	0	1	1	CR	B1+2c	2006	1
Astragalus nitidiflorus	6		1	CR	B1ac (IV)+2ac (IV) ; C2a (I,II); D	2006	0
Astragalus peterfii	0	1					
Astragalus physocalyx	0	1					
Astragalus psedopurpureus	0	1					
Astragalus raphaelis	0		1	CR	A1ce	2006	0
Astragalus setosulus	0	1					
Astragalus tanaiticus	0	1					
Astragalus thermensis	0		1	CR	A1,B1	2004	0
Astragalus tremolsianus	3	1	1	CR	B1ab I)+2ab (III)	2006	1
Astragalus verrucosus	2	1	1	CR	B1ab (I,II,III)	2006	1
Asyneuma comosiforme	0		1	CR		2006	0

Asyneuma giganteum	8	1						
Athamanta cortiana	0	1						
Atractylocarpus alpinus	16	1						
Atriplex tatarica var. constantinapolitana	0		1	CR		2006	0	
Atropa baetica	47	1						
Aurinia uechtritziana	0	1						
Avellara fistulosa	2		1	CR	B1ab (I,II,III,IV,V)+2ab (I,II,III,IV,V)	2006	0	
Avenula hackelii subsp. *algarbiensis*	0		1	CR	B1+2c	2006	0	
Avenula hackelii subsp. *hackelii*	0	1	1	CR	B1+2c	2006	0	
Bassia (Kochia)	8		1	CR	C2b	2006	1	
Bellevalia edirnensis	0		1	CR		2006	1	
Beta adanensis	0	1						
Beta trojana	2	1						
Betula klokovii	0		1	CR	D	2006	0	
Biarum fraasianum	0		1	CR	B1+2abc((i,ii,iii,iv,v); C2(a1);D	2006	1	
Biarum mendax	0		1	EW		2004	1	
Biscutella divionensis	49		1	CR	D	2006	1	
Biscutella neustriaca	30	1						
Biscutella rotgesii	1		1	CR	B1ab (III,IV) + 2ab I,IV)	2004	1	
Biscutella vincentina	3							
Bolanthus intermedius	1		1	CR	B2c+3c	2006	0	
Boleum asperum	13	1						
Borago morisiana	0		1	CR	C1	2006	1	
Borderea chouardii	2	1	1	CR	B2ab (V)	2006	1	
Botrychium matricariifolium	822	1						
Botrychium multifidum	897	1						
Botrychium simplex	461	1						
Brassica cadmea	2		1	EX		2006	0	
Brassica glabrescens	2	1	1	CR	E	2004	0	
Brassica hilarionis	0	1						
Brassica insularis var. aquellae	0	1	1	CR	B1+2c ; C2b ; D	2006	1	
Brassica insularis var. latiloba	0	1	1	CR	B1+2c ; D	2006	1	

Brassica macrocarpa	3	1			1	CR	B2c+3c	2006	2
Brassica sylvestris subsp. *taurica*	0	1			1	CR		2006	1
Brassica tyrrhena	0				1	CR	D	2004	1
Braya linearis	255								
Braya purpurasceus	0	1							
Brimeura duvigneaudii	1				1	CR	B1ab (IV,V)+2ab (IV,V) ; C2a (I) ; D	2004	1
Bromus bromoideus	0	1			1	EW		2006	2
Bromus grossus	102	1			1	CR	A1ac	2006	2
Bromus interruptus	261	1			1	EW		2006	2
Bromus moesiacus	0	1							
Bromus psammophilus	3	1							
Bromus pseudosecalinus	70				1	CR	A2c, E	2006	1
Bruchia vogesiaca	79	1							
Bryhnia nova	0								
Bryoerythrophyllum campylocarpum	161								
Bufonia euboica	0				1	CR	B1+2c	2006	0
Buphthalmum inuloides	0				1	CR	B1+2c; E	2004	1
Bupleurum capillare	5	1							
Bupleurum dianthifolium	1	1	CR	B1ab(iii)+2ab(iii)	1	CR	B1ab (III) + (III)	2004	1
Bupleurum elatum	0				1	CR	B1ab (III) + 2ab (III)	2004	1
Bupleurum kakiskalae	3	1	CR	B1ab(iii,v)c(iv)+2ab(iii,v)c(iv); C2a(ii)b; D	1	CR	B1ab (III,V) V) + 2ab (III,V) c(iv)C2a(ii)b.D	2006	1
Buxbaumia viridis	588	1							
Calamagrostis chalybaea	98								
Calamintha sandaliotica	0				1	CR	B1ab (II,III,V) + 2ab (II,III,V) ; C2a (II)	2006	0
Caldesia parnassifolia	426	1							
Calendula maritima	0				1	CR	B1ab (III) + 2ab (III)	2004	1
Callitriche pulchra	0				1	CR	B1+2c	2006	0
Calypso bulbosa	358								
Camelina alyssum	489				1	CR	A1a,c	2006	4
Campanula abietina	2	1							
Campanula bohemica subsp. *gelida*	0				1	CR	B1+3c ; D	2006	1
Campanula calycialata	0				1	CR	A1bc ; D	2006	0
Campanula damboldtiana	0	1							

Campanula gelida	0	1						
Campanula lanata	1	1						
Campanula lycica	0	1						
Campanula marcenoi	0			1	CR	B1+2c ; D	2004	0
Campanula morettiana	25	1						
Campanula romanica	0	1						
Campanula sabatia	3	1						
Cardaminopsis pedemontana	0			1	CR	A1ac	2006	0
Carduncellus matritensis	0			1	EX		2006	0
Carduus myriacanthus	12	1						
Carduus rugulosus	0			1	CR	C1, E	2006	0
Carex holostoma	164							
Carex markgraffii	0			1	EX		2006	0
Carex panormitana	0			1	CR	B2c+3c	2006	0
Carex secalina	30	1						
Carex viridula subsp. *pseudoscandinavica*	0			1	CR	B1+2c	2006	1
Carlina diae	8	1		1	CR	B1+2c	2006	1
Carlina onopordifolia	5	1						
Carthamus tenuis subsp. *gracillimus*	0			1	CR	D	2006	0
Castrilanthemum debeauxii	1			1	CR	B1abc+2abc	2006	0
Caulerpa ollivieri	0	1						
Caulinia tenuissima	0	1						
Centaurea aetolica	1			1	CR	B1+2abc	2006	1
Centaurea akamatis	0	1		1	CR	B1ab (III) + 2ab (III)	2006	1
Centaurea alba subsp. *heldreichii*	0	1						
Centaurea alba subsp. *princeps*	0							
Centaurea appendicata	0			1	CR		2006	0
Centaurea attica subsp. *megarensis*	0	1						
Centaurea balearica	3	1						
Centaurea borjae	7	1						
Centaurea charrelii	0			1	CR	A2a 1+2cd ; C2ab ; D	2006	0
Centaurea citricolor	18	1						

Centaurea corymbosa	16	1						
Centaurea dubjanskyi	0	1						
Centaurea gadorensis	14							
Centaurea haenseleri subsp. *epapposa*	0		1	CR	B1ab(2,3)+2ab(2,3) ; C2a(2)	2006	0
Centaurea heldreichii	0		1	CR	B1+2c ; C2a	2006	1
Centaurea hermannii	0	1					
Centaurea horrida	0	1					
Centaurea incompleta	1		1	CR	C2ab ; D	2006	0
Centaurea jacea subsp. *forojulensis*	0		1	CR	E	2004	0
Centaurea jankae	0	1	1	CR	B2c+3c	2006	1
Centaurea kalambakensis	9	1					
Centaurea kartschiana	0	1					
Centaurea konkae	0		1	CR		2006	0
Centaurea kunkelii	7		1	CR	B1ab(3)+2ab(3)	2006	0
Centaurea lactiflora	2	1	1	CR	B1+ 2c	2006	1
Centaurea lactucifolia var. halkensis	0		1	CR	B1+ 3c	2006	0
Centaurea lainzii	22		1	CR	B1ab(2,5) ; (1) ; D	2006	1
Centaurea margaritacea	1		1	CR		2006	1
Centaurea margaritalba	0		1	CR		2006	0
Centaurea micrantha subsp. *herminii*	0						
Centaurea montisborlae	0		1	CR	B1+2c	2004	0
Centaurea niederi	5	1					
Centaurea paczoskii	0		1	CR		2006	0
Centaurea peucedanifolia	0	1	1	CR		2006	0
Centaurea pineticola	0	1					
Centaurea pinnata	5	1					
Centaurea pinnatifida subsp. *sooana*	0		1	EX		2006	0
Centaurea pontica	0	1	1	CR	B2c+3c	2006	1
Centaurea princeps	4		1	CR	B1+2c	2006	0
Centaurea proto-gerberi	0		1	CR		2006	0
Centaurea protomargaritacea	0		1	CR		2006	0
Centaurea pseudoleucolepis	0	1	1	CR		2006	1

Centaurea pulvinata	2	1							
Centaurea rothmalerana	2								
Centaurea tchihatcheffii	0	1							
Centaurea tuntasia	1				1	EX		2006	0
Centaurea ultreiae	7				1	CR	B1+2,b(1,2,3,5)	2006	1
Centaurea vicentina	0								
Centaurium favargeri	2				1	CR	A1a;B1+2a,b,c,d,e;D	2005	1
Centaurium rigualii	0	1							
Centaurium somedanum	5	1							
Centranthus amazonum	0				1	CR	D	2006	1
Centranthus kellererii	0	1							
Centranthus trinervis	3	1	CR	B1ac(iv)+2ac(iv); C2b	1	CR	B1ac (IV) + 2ac (IV) ; C2b	2006	1
Cephalanthera cucullata	3	1			1	CR	A1ac	2006	0
Cephalaria demetrii	0				1	CR		2004	0
Cephalaria litvinovii	0				1	CR	B2a+3e	2006	2
Cephalaria squamiflora subsp. *ebusitana*	0				1	CR	B1ab(3,5)+2ab(3,5) ; C2a(1), D	2006	0
Cephalaria tenuiloba	1				1	CR	B1+2c	2006	1
Cephalozia macounii	6	1							
Cerastium alsinifolium	0	1			1	CR	B2a+3cd	2006	1
Cerastium illyricum subsp. *crinitum*	0				1	EX		2006	0
Cerastium neoscardicum	0				1	CR	B1	2006	0
Cerastium soleirolii	2				1	CR	A3 ab ; B1,2 I,II,IV)	2004	0
Cerastium vagans var. ciliatum	0				1	EX		2006	0
Cerasus klokovii	0				1	CR	D	2006	1
Ceratocapnos claviculata subsp. *picta*	0				1	CR		2006	0
Chaenorrhinum minus subsp. *pseudorubrifolium*	0				1	CR	+2c, D	2006	1
Chaenorrhinum serpyllifolium subsp. *lusitanicum*	0								
Chaetopogon fasciculatus subsp. *prostratus*	0				1	CR	B2b (II,III,IV,V) c(II,IV)	2004	0
Chamaecytisus nejceffii	0				1	CR		2006	0
Cheirolophus crassifolius	0				1	CR	B1ab (I,II,III,IV,V)	2004	3

Chenopodium wolffii	0				1	EX		2006	0
Chionodoxa lochiae	1	1							
Chionodoxa luciliae	48	1							
Chrysochamela draboides	0				1	CR		2006	0
Cinna latifolia	1136								
Cirsium steirolepis	3				1	CR	B1+2c	2006	0
Cistus heterophyllus subsp. *carthaginensis*	0				1	CR	A2ce ; B1ab(5)+2ab(5) ; C2a(2),D	2006	1
Cistus palhinhae	11								
Clematis elisabethae-carolae	2				1	CR	A1ac	2006	1
Clypeola eriocarpa	2				1	CR	B1ab(1,4) 2ab(1,4)	2006	1
Cochlearia borzaeana	0				1	CR	B2ab+3e	2006	0
Cochlearia macrorrhiza	0				1	EW		2006	1
Cochlearia polonica	1	1			1	CR	EW	2006	1
Coincya rupestris	30	1			1	CR	B2ac4	2006	1
Colchicum arenarium	3	1							
Colchicum arenasii	0				1	CR	A2a,c,d	2004	1
Colchicum callycimbium	0				1	CR		2004	4
Colchicum corsicum	2	1							
Colchicum cousturieri	0	1							
Colchicum davidovii	0	1							
Colchicum fominii	0	1							
Colchicum micranthum	0	1							
Colchicum pieperanum	0				1	CR	A1b	2006	0
Coleanthus subtilis	150	1							
Comperia comperiana	1	1							
Consolida samia	3	1	CR	B1ab(iii,v)+2ab(iii,v)	1	CR	B1ab (III,V) ab (III,V)	2006	0
Consolida uechtritziana	0				1	EX		2006	0
Convolvulus argyrothamnos	2	1	CR	B1ab(ii,v)+2ab(ii,v); C2a(i); D	1	CR	B1ab (II,V) + 2ab (II,V) ; C2a (I) D	2006	1
Convolvulus fernandesii	0								
Convolvulus pulvinatus	0	1							
Convolvulus sabatius subsp. *sabatius*	0				1	CR	A1c	2006	1
Corispermum gallicum	0				1	CR	A1;B1,2a(i,ii,iii,iv,v);E	2006	1

Coronopus navasii	11	1			1	CR	B1b (IV,V)+2b (IV,V) IV)	2006	1
Cortusa matthioli subsp. *moravica*	0				1	CR	B1+3e	2006	1
Corydalis gotlandica	6								
Cotoneaster cambricus	39				1	CR	B1+2c ; D	2006	2
Cotoneaster raboutensis	0				1	CR	B1+2c ; D	2006	2
Crambe koktebelica	0	1							
Crambe litwinonowii	0	1			1	CR		2006	1
Crassula basaltica	0				1	CR	B1+2c	2006	0
Crataegus dikmensis	0	1							
Crataegus karadaghensis	0				1	CR		2004	0
Crataegus pojarkovae	0				1	CR		2006	1
Cremnophyton lanfrancoi	0	1	CR	B1ab(i,ii,iii,iv,v)	1	CR	B1ab (I,II,III,IV,V)	2004	2
Crepis arcuata	1				1	CR	B1+2c	0 garden	0
Crepis crocifolia	1	1							
Crepis foliosa	0				1	EX		2006	0
Crepis granatensis	7	1							
Crepis novoana	1				1	CR	B1b (I,II,III,IV,V) ; C (II,IV)	2006	1
Crepis purpurea	0	1							
Crepis tectorum subsp. *nigrescens*	0								
Crocus abantensis	0	1							
Crocus cyprius	1	1							
Crocus etruscus	1	1							
Crocus hartmannianus	1	1							
Crocus robertianus	0	1							
Crocus rujanensis	0				1	CR	B1+2ce	2006	1
Crypsis hadjikyriakou	0				1	CR	B1a + b (III) (III)	2006	0
Culcita macrocarpa	110	1							
Cuscuta epilinum	483				1	CR	A1a,c	2006	2
Cyclamen coum	102	1							
Cyclamen kuznetzovii	0	1							
Cyclamen mirabile	0	1							
Cymbalaria fragilis	0				1	CR	B1ab (III,V) + 2ab (III,V) ; C2a (I) ; D	2004	1

Cymodocea nodosa	22	1							
Cynodontium suecicum	104	1							
Cypripedium calceolus	3906	1							
Cystoseira amentacea	42	1							
Cystoseira mediterranea	54	1							
Cystoseira sedoides	0	1							
Cystoseira spinosa	32	1							
Cystoseira zosteroides	21	1							
Cytisus aeolicus	2	1							
Dactylorhiza chuhensis	2	1							
Dactylorhiza elata subsp. *brennensis*	0				1	CR	A2a,c	2006	0
Dactylorhiza pythagorae	0				1	CR	B1+2c	2006	0
Daphne arbuscula	2	1							
Daphne petraea	14	1							
Daphne reichsteinii	0				1	CR	D ; E	2004	2
Daphne rodriguezii	3	1							
Daphne taurica	0				1	CR		2006	1
Daucus conchitae	0				1	CR	B1+2c	2006	0
Delphinium caseyi	0	1	CR	B1ab(iii,v)+2ab(iii,v)	1	CR	B1ab (III,V) + 2ab (III,V)	2006	0
Delphinium fissum subsp. *sordidum*	0				1	CR	B2ac (II,III,IV) ; C2a (I) ; B	2006	0
Delphinium longipes	0				1	CR	B1ab (III,IV,V) + 2ab (I,II,III,IV,V)	2004	0
Delphinium pentagynum subsp. *formenteranum*	0				1	CR	A3c B1ab (I,II,III) + 2ab (I,II,III)	2006	1
Dendranthema zawadskyi	0	1							
Dianthus arenarius subsp. *arenarius*	0								
Dianthus arenarius subsp. *bohemicus*					1	CR	B1+2abce	2006	1
Dianthus carthusianorum subsp. *sudeticus*	0				1	CR	B1+2c	2006	1
Dianthus cintranus subsp. *cintranus*	0								
Dianthus dobrogensis	0				1	CR		2006	0
Dianthus fruticosus subsp. *karavius*	0				1	CR	B1+2c	2006	0
Dianthus gasparrinii	0				1	CR	B1+2c; D	2004	0
Dianthus hypanicus	0	1							

Dianthus ingoldbyi	0				1	CR		2006	0
Dianthus juniperinus subsp. *kavusicus*	0				1	CR	B1+2c	2006	0
Dianthus marizii	2								
Dianthus morisianus	0				1	CR	B1ab (I,II,III) b (I,II,III)	2004	1
Dianthus multinervis	0				1	EX		2006	0
Dianthus nitidus	2	1							
Dianthus pratensis subsp. *racovitzae*	0				1	CR		2006	0
Dianthus rupicola	13	1							
Dianthus serotinus	6	1							
Dianthus urumoffii	0	1			1	CR	B1+2ab	2006	0
Dichelyma capillaceum	95	1							
Dicranum viride	401	1							
Digitalis leucophaea subsp. *ikarica*	0				1	CR	B1+2c	2006	0
Diplazium sibiricum	150								
Diplotaxis ibicensis	56	1							
Diplotaxis siettiana	3	1	CR	B1ac(iv)+2ac(iv)	1	CR	B1ac (IV) + 2ac (IV)	2006	1
Diplotaxis vicentina	4								
Dipsacus cephalarioides	0	1							
Distichophyllum carinatum	2	1	EN	B1+2c, C2a					
Draba cacuminum	76								
Draba cinerea	218								
Draba dorneri	0	1			1	CR		2006	0
Draba simonkaiana	0				1	CR		2006	0
Dracocephalum austriacum	105	1							
Dracocephalum ruyschiana	565	1							
Drepanocladus vernicosus	94								
Dryopteris corleyi	50	1							
Dryopteris fragans	0								
Echinospartum algibicum	9				1	CR	B1ab (III,V) + 2ab(III,V) ; C2a(II)	2006	1
Elatine gussonei	1				1	CR	B1+2c ; D	2004	1
Eleocharis carniolica	35	1							
Encalypta mutica	42								

Epipactis mecsekensis	0				1	CR	D	2006	0
Eranthis hyemalis var. bulgaricus	0				1	CR	B1+2c	2006	0
Eremoblastus caspicus	0				1	CR		2006	0
Eremopoa mardinensis	0	1							
Eremurus jungei	0				1	CR		2006	0
Erigeron frigidus	5	1							
Erigeron paolii	0				1	CR	A2c	2004	1
Erodium astragaloides	4	1			1	CR	B1ab(3,5)+ab(3,5)	2006	1
Erodium betekowii	0				1	CR		2006	1
Erodium chrysanthum	2	1							
Erodium paularense	9	1							
Erodium rupicola	15	1							
Erucastrum palustre	0	1			1	CR	B1+2abc	2006	1
Eryngium alpinum	185	1							
Eryngium viviparum	33	1							
Erysimum krynkense	0				1	CR		2006	0
Erysimum kykkoticum	0				1	CR	B1a + B (V) B2a + B (V)	2004	0
Erysimum pieninicum	0	1							
Erysimum witmannii subsp. *pallidiflorum*	0				1	CR		2006	1
Euphorbia fontqueriana	2				1	CR	B1ab (III,V) + 2ab(III,V), C2a(II)	2006	1
Euphorbia gaditana	7				1	CR	B2ab(1,2,3,4,5)	2006	1
Euphorbia margalidiana	2	1	CR	B1ab(v)+2ab(v)	1	CR	B1ab(5)+2ab(5)	2006	2
Euphorbia nevadensis	32	1							
Euphorbia stygiana subsp. *santamariae*	0				1	CR	D	2006	0
Euphorbia transtagana	2								
Euphrasia genargentea	0				1	CR	B1+3c	2006	0
Euphrasia grandiflora	2				1	CR	B2abde, C1	2006	0
Euphrasia marchesettii	4	1							
Euphrasia mendoncae	0				1	CR		2006	0
Evax carpetana var. gallica	0				1	CR	A1c	2006	0
Femeniasia balearica	0				1	CR	B1ab (III,V) + 2ab (III,V)	2004	1
Ferula halophila	2	1							

Ferula orientalis	0	1						
Ferula sadlerana	1		1	CR	A1c	2006	2	
Ferula sadleriana	1	1						
Festuca brigantina	11							
Festuca duriotagana	3		1	CR	B1+2a	2006	0	
Festuca elegans	97							
Festuca gautieri subsp. *lutea*	0		1	EX		2006	0	
Festuca henriquesii	2							
Festuca pseudosupina	1		1	CR	A1ac	2006	0	
Festuca pulchella subsp. *scheuchzeriformis*	0		1	EX		2006	0	
Festuca summilusitana	3							
Fritillaria conica	0	1	1	CR	A1ac	2006	2	
Fritillaria drenovskii	3	1						
Fritillaria epirotica	1	1						
Fritillaria euboeica	0	1						
Fritillaria graeca	35	1						
Fritillaria gussichiae	1	1						
Fritillaria montana	3	1						
Fritillaria obliqua	1	1						
Fritillaria rhodocanakis	6	1						
Fritillaria thessala subsp. *reiseri*	0		1	CR	A1ac	2006	1	
Fritillaria tuntasia	0	1						
Frullania parvistipula	0	1						
Fumaria jankae	0		1	EX		2006	0	
Galium cracoviense	0	1						
Galium globuliferum	0	1						
Galium litorale	0	1						
Galium moldavicum	0	1						
Galium rhodopeum	4	1						
Galium viridiflorum	37	1						
Gaudinia hispanica	4	1						
Genista demarcoi	0		1	CR	B2c+3c	2006	0	

Genista dorycnifolia	3	1						
Genista dorycnifolia subsp. *grosii*	0		1	CR	B1ab (III,V) + 2ab (III,V), C2a(II)	2006	1
Genista gasparrini	0		1	CR	B1+2c	2006	1
Genista holopetala	2	1					
Genista melia	0		1	EX		2006	0
Genista tetragona	0	1	1	CR		2006	0
Genista toluensis	0		1	CR	B1+2c; C1; E	2004	0
Gentiana ligustica	68	1					
Gentiana pneumonanthe subsp. *nopcsae*	0		1	CR	B2bcd	2006	0
Gentianella anglica	926	1					
Geocaryum bornmuelleri	1		1	EX		2006	0
Geocaryum divaricatum	0		1	EX		2006	0
Geranium cazorlense	15		1	CR	B1ab (III,V) b (III,V)	2006	1
Geum bulgaricum	0	1					
Geum micropetalum	0		1	CR	A1ac	2006	0
Gladiolus felicis	0	1	1	EW		2006	1
Globularia stygia	0	1					
Glycyrrhiza iconica	0	1					
Goniolimon italicum	0		1	CR	E	2004	1
Goniolithon byssoides	0	1					
Grammitis marginella subsp. *azorica*	0		1	CR	D	2006	0
Gymnigritella runei	3						
Gymnospermium scipetarum	0		1	CR	A1a	2006	0
Gypsophila papillosa	2	1	1	CR	B1+2c	2006	1
Gyrocaryum oppositifolium	3		1	CR	B1+2a	2006	0
Haberlea rhodopensis	10	1					
Halimium verticillatum	0						
Hamatocaulis lapponicus	21						
Haplophyllum bastetanum	0		1	CR	A2 acd B2 ab (I,II,III,IV,V) C2a (I)	2006	0
Hedysarum razoumovianum	0	1					
Hedysarum ucrainicum	0		1	CR		2006	0
Helianthemum alypoides	42	1					

Helianthemum arcticum	0	1							
Helianthemum caput-felis	126	1							
Helianthemum polygonoides	8				1	CR	B1ab (III)+2ab(III)	2006	1
Helianthemum scopulicolum	2				1	CR	B1ab (IV,V) + 2ab(IV,V) ; C2a(II), D	2006	1
Helichrysum melitense	0	1	CR	B1ab(i,ii,iii,iv,v)	1	CR	B1ab (I,II,III,IV,V)	2004	1
Helichrysum sibthorpii	4	1							
Helichrysum taenari	1				1	CR	B1+3c	2006	1
Heptaptera macedonica	0				1	CR		2006	0
Heracleum pubescens	4				1	CR		2006	2
Herniaria algarvica	3	1							
Herniaria ciliolata subsp. *subciliata*	0				1	EX		2006	0
Herniaria fontanesii subsp. *empedocleana*	0				1	CR	B1+2c	2006	0
Herniaria latifolia subsp. *litardierei*	0				1	CR	A2b	2006	0
Herniaria lusitanica subsp. *berlengiana*	0								
Herniaria maritima	24	1							
Herzogiella turfacea	127								
Hieracium bertisceaum	0				1	CR	B1	2006	0
Hieracium calvum	3				1	CR	D	2006	1
Hieracium chaixianum	0				1	CR	B1	2004	0
Hieracium cophanense	0				1	CR	B1+2c	2006	1
Hieracium eriophorum var. eriophorum	0				1	CR	A1,B1,2ab(i,ii,iii,iv,v);C1a(i)	2006	0
Hieracium graniticola	10				1	CR	D	2006	1
Hieracium grovesii	13				1	CR	D	2006	1
Hieracium hanburyi f. pusillum	0				1	CR	D	2006	1
Hieracium insigne	10				1	CR	D	2006	1
Hieracium lucidum	0				1	CR	B1ab (I,II,III,V) + B2ab (I,II,III,V)	2006	1
Hieracium optimum	8				1	CR	B1+2, D	2006	0
Hieracium pseudocurvatum	13				1	CR	D	2006	0
Hieracium queraltense	1				1	CR	D	2006	0
Hieracium radyrense	2				1	CR	D	2006	1
Hieracium recoderi	2				1	CR	D	2006	0

Hieracium snowdowniense	0		1	CR	A1a, D	2006	1
Hieracium texedense	8		1	CR	B1ab(III,IV) (III,V)	2006	1
Hieracium vinyalsianum	0		1	CR	B1ab(III,V)+2ab(III,V) c(IV) ; C2a(II)b	2006	0
Himantoglossum caprinum	6	1					
Hippocrepis prostrata	1		1	CR	B1ab(III)+2ab(III)	2006	1
Hippocrepis tavera-mendozae	2		1	CR	B1ab(III,IV,V)+2ab(III,IV,V) ; C2a(I)	2006	0
Hippuris tetraphylla	127						
Holcus notarisii	0		1	EX		2004	0
Holcus setiglumis subsp. *duriensis*	0						
Horstrissea dolinicola	0		1	CR	B1ab (II,V) + 2ab (II,V) ; C2a (I) ; D	2006	1
Hyacinthoides vicentina	3						
Hygrohypnum montanum	93						
Hymenostemma pseudanthemis	6	1					
Hypericum aciferum	1	1	1	CR	C2a	2006	1
Hypericum salsugineum	2	1					
Hypericum setiferum	0		1	EX		2006	0
Hypochoeris rutea	3		1	CR	B1ab II,III,V)+2ab(I,II,III,V)	2006	1
Iberis arbuscula	0	1					
Iberis integerrima	0		1	CR	B1+2c; D	2004	1
Iberis intermedia subsp. *beugesiaca*	0		1	CR	D	2006	1
Iberis procumbens subsp. *microcarpa*	0						
Iberis runemarkii	4		1	CR	B1+2c, D	2006	0
Iberis timeroyii	0		1	CR	D	2006	1
Ionopsidium acaule	2	1					
Ionopsidium savianum	4	1					
Iris erirrhiza	0		1	CR		2004	1
Iris marsica	3	1					
Iris revoluta	0		1	CR	B1+2c, D	2006	1
Isatis grammotis	0		1	CR	D	2006	0
Isatis vermia	0		1	CR	B1+2c	2006	0
Isoetes boryana	18	1					
Isoetes heldreichii	0		1	CR	A1c	2006	0

Isoetes malinverniana	2	1			1	CR	A2c, B2c	2006	2
Jankaea heldreichii	6	1							
Jasione crispa subsp. *serpentinica*	0								
Jasione heldreichii var. papillosa	0				1	CR		2006	0
Jasione lusitanica	7	1							
Jonopsidium acaule	17								
Jonopsidium savianum	20								
Juncus valvatus	2								
Jungermannia handelii	0	1							
Jurinea cyanoides	107	1							
Jurinea fontqueri	8	1			1	CR	A3c b(III,V)+2ab(III,V)	2006	1
Kalidiopsis wagenitzii	0	1							
Knautia arvensis subsp. *pseudolongifolia*	0				1	CR	B1+2c	2006	1
Knautia kitaibelii subsp. *tomentella*	0				1	CR		2006	0
Kochia saxicola	0	1							
Kosteletzkya pentacarpos	42	1							
Lagoseris purpurea	0	1							
Laminaria ochroleuca	105	1							
Laminaria rodriguezii	22	1							
Lamium glaberrimum	0				1	CR		2006	0
Lamium purpureum var. aznavourii	0				1	CR		2006	0
Lamyropsis microcephala	0	1	CR	B1ab(iii)+2ab(iii)	1	CR	B1ab (III) + 2ab (III) ; D	2006	0
Lanfranco	0				1	EX		2006	0
Laserpitium latifolium subsp. *nevadense*	0				1	CR	A2cd ; B1+2c	2006	0
Laserpitium longiradium	4	1			1	CR	A2cd, B1+2c	2006	1
Lathyrus nissolia subsp. *futakii*	0				1	CR		2006	0
Lathyrus pancicii	0				1	CR	B1+2c	2006	0
Lavatera plazzae	0				1	CR	B1+2c; E	2004	0
Lavatera triloba subsp. *pallescens*	0				1	CR	B1+2c	2006	1
Legousia hybrida var. foliosa	0				1	EX		2006	0
Leontodon boryi	10	1							
Leontodon microcephalus	8	1							

Leontodon siculus	3	1						
Lepidium turczaninowii	0	1	1	CR		2006	0
Leucanthemum vulgare subsp. *meridionale*	0		1	CR	D	2006	1
Leucojum nicaeense	61	1					
Leuzea longifolia	1		1	CR	B1+2abcde	2006	1
Ligularia sibirica	345	1					
Ligusticum albanicum	0		1	CR		2006	0
Ligusticum huteri	0		1	CR	B1ab (V) + 2ab (V) ; (II)	2006	1
Lilium jankae	7	1					
Lilium rhodopaeum	3	1					
Limonium aegusae	0		1	CR	B1+2c	2006	1
Limonium albomarginatum	0		1	CR	B1+2c	2006	0
Limonium anatolicum	2	1					
Limonium aphroditae	0		1	CR	B1+2c	2006	0
Limonium aragonense	4		1	CR	B1ab(I,II,IV)+2ab(I,II,IV)	2006	0
Limonium barceloi	2		1	CR	B1ab (III,V) +2ab (III,V)	2006	0
Limonium bellidifolium subsp. *dubyi*	0		1	EX		2006	0
Limonium calcarae	0		1	CR	D	2004	1
Limonium carvalhoi	1		1	CR	B1ab (III,V) + 2ab(III,V) ; C2a(II)	2006	0
Limonium catalaunicum	19		1	CR	B1ab (I,II,III,IV,V)c(I,II,III)+2ab(I,II,III,IV,V) ; C	2004	0
Limonium catanense	0		1	EX		2006	0
Limonium catanzaroi	0		1	CR	B1+2c	2006	1
Limonium coronense	0		1	CR	B1+2c	2006	0
Limonium dodartii subsp. *lusitanicum*	0						
Limonium dufourii	52		1	CR	A3ce ; B1ab (III,IV,V) + 2ab (III,IV,V)	2006	1
Limonium ejulabilis	1		1	CR	B1ab (III,V) + 2ab (III,V)	2006	0
Limonium estevei	20		1	CR	B1ab (III,V) + 2ab (III,V)	2006	1
Limonium inexpectans	2		1	CR	B1ab (II,III,IV,V) + 2ab 5II,III,IV,V) ; C2a (I); D	2006	0
Limonium insulare	0						
Limonium intermedium	0		1	EW		2006	1
Limonium lanceolatum	7						

Limonium leonardi-llorensii	1		1	CR	B1ab (III,V) + 2ab (III,V) ; C2a(I) ; D	2006	0
Limonium magallufianum	5		1	CR	B1ab (III,V) + 2ab(III,V)	2006	1
Limonium majoricum	6		1	CR	B1+2abc	2006	1
Limonium melancholicum	0		1	CR	B1+2c; D	2004	1
Limonium merxmuelleri	0		1	CR	B1ab (I,II,III,IV,V) + 2ab (I,II,III,IV,V)	2004	1
Limonium messeniacum	0		1	CR	B1+2c	2006	0
Limonium migjornense	5		1	CR	B1ab (III) + 2ab (III)	2006	0
Limonium multiflorum	0						
Limonium opulentum	0		1	CR	B1+2c; D; E	2004	0
Limonium pachynense	0		1	CR	B1+2c	2006	1
Limonium panormitanum	0		1	CR	D	2004	0
Limonium perplexum	8		1	CR	A3c ; B1ab (III,V)c (III) + 2ab (III,V) c3 ; C2a (II)	2006	1
Limonium peucetium	0		1	EX		2006	0
Limonium pseudodictyocladium	0		1	CR	B1ab (III,V) + 2ab (III,V) ; C2a (II)	2006	1
Limonium pseudolaetum	0						
Limonium pulviniforme	0		1	CR	B1+2c	2006	0
Limonium sibthorpianum subsp. *sibthorpianum*	0		1	CR	B1+2c	2006	1
Limonium soboliferum	2		1	CR	A4bc ; B1ab (III) +2ab (II,III)	2004	0
Limonium strictissimum	0		1	CR	B1ab(III,V) + 2ab (III,V)	2006	1
Limonium tamaricoides	2	1					
Limonium tarcoense	0		1	CR	B1+2c	2006	0
Limonium tauromenitanum	0		1	CR	B1+2c	2006	1
Limonium todaroanum	0		1	CR	B1+2c	2006	1
Limonium vigoi	2		1	CR	B1ab (I,II,III,IV,V)	2006	1
Linaria algarviana	6	1					
Linaria benitoi	12		1	CR	B1ab II,III,V) c (I,II,IV)+2ab (I,II,III,V) ; C	2004	0
Linaria coutinhoi	1		1	CR		2006	0
Linaria ficalhoana	4	1					
Linaria flava	15	1					
Linaria hellenica	0	1					
Linaria loeselii	3	1					
Linaria pseudolaxiflora	1	1					

Linaria ricardoi	0	1			1	CR	A1ac, E	2006	1
Linaria tonzigii	2								
Linaria tursica	3	1							
Lindernia procumbens	745	1							
Linum dolomiticum	5	1			1	CR	B1+3e	2006	2
Linum muelleri	0				1	CR	B1ab (I,II,II,IV,V) + (I,II,III,IV,V)	2004	0
Linum pallasianum subsp. *borzeanum*	0				1	CR	D	2006	0
Linum phitosianum	1				1	CR	B1+2c, C2a	2006	0
Linum tauricum subsp. *bosphori*	0				1	CR		2006	0
Liparis loeselii	2932	1							
Lithodora nitida	13	1	EN	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)					
Lithophyllum lichenoides	76	1							
Logfia neglecta	2				1	EX		2006	0
Lolium remotum	533				1	CR	A1abc	2006	3
Lomelosia minoana subsp. *asterusica*	0				1	CR	B1+2c	2006	0
Lunaria telekiana	0				1	CR	B2a	2006	0
Lupinus mariae-josephi	6				1	EW		2006	1
Luronium natans	3657	1							
Luzula arctica	101								
Lysimachia minoricensis	1	1	EW		1	EW		2006	3
Lythrum flexuosum	21	1							
Lythrum thesioides	3	1							
Lythrum thesioides subsp. *thesioides f. 'Europe'*	0				1	CR	A2ac, B1+3ab	2006	1
Mandragora officinarum	3	1							
Mannia triandra	13	1							
Marsilea azorica	0				1	CR	B1+3abce	2006	3
Marsilea batardae	93	1							
Marsilea quadrifolia	1221	1							
Marsilea strigosa	145	1							
Marsupella profunda	31	1	LR/lc						
Meesia longiseta	79	1							

Melilotus segetalis subsp. *fallax*	0								
Microcnemum coralloides subsp. *anatolicum*	0	1							
Micromeria taygetea	0	1							
Micropyropsis tuberosa	10	1							
Minuartia athoa subsp. *neoiraklitsa*	0				1	CR	B1+2c	2006	0
Minuartia dirphya	0				1	CR	B1ab (III,V) + 2ab (III,V)	2004	1
Minuartia greuteriana	3				1	CR	B1+2c	2006	0
Minuartia moraldoi	0				1	CR	B1+2c ; C2b	2004	1
Minuartia parnonia	0				1	CR	A1c, B1+2c	2006	0
Minuartia smejkalii	0	1			1	CR	A1a	2006	0
Minuartia wettsteinii subsp. *wettsteinii*	0				1	CR	A1c, B1+2c	2006	0
Moehringia fontqueri	3	1	EN	B1ac(iv)+2ac(iv)					
Moehringia hypanica	0	1			1	CR		2004	0
Moehringia intricata subsp. *tejedensis*	0				1	CR	B1ab(III)	2006	1
Moehringia jankae	3	1							
Moehringia lateriflora	816								
Moehringia tommasinii	5	1							
Murbeckiella sousae	0	1							
Muscari gussonei	3	1							
Myosotis azorica	7				1	CR	B2d+3de,	2006	1
Myosotis lusitanica	3								
Myosotis praecox	7	1							
Myosotis refracta subsp. *aegagrophila*	0				1	CR		2006	0
Myosotis rehsteineri	173	1			1	EN	B1+2abcd CR (1994))	2006	3
Myosotis retusifolia	3								
Myosotis solange	0				1	CR	B1+2c	2006	0
Najas flexilis	1157	1							
Najas tenuissima	12	1							
Narcissus angustifolius	0	1							
Narcissus asturiensis	153								
Narcissus calcicola	6								

Narcissus cyclamineus	29								
Narcissus fernandesii	41								
Narcissus humilis	3								
Narcissus longispathus	19	1	EN	B1b(iii,v)c(iv)+2b(iii,v)c(iv)					
Narcissus nevadensis	18	1							
Narcissus nevadensis subsp. *enemeritoi*	0				1	CR	B1ab (III,IV,V)+2ab, C1+2a (II)	2006	0
Narcissus pseudonarcissus subsp. *nobilis*	0								
Narcissus scaberulus	0	1							
Narcissus triandrus	162	1							
Narcissus triandrus subsp. *capax*	0				1	VU	CR (1990))	2004	2
Narcissus viridiflorus	2	1							
Naufraga balearica	6	1	CR	B1ab(v)+2ab(v)	1	CR	B1ab (V) +2ab (V)	2004	2
Nepeta amethystine subsp. *anticaria*	0				1	CR	B1ab(II,III,V)+2ab(II,III,V)	2006	1
Nepeta dirphya	0	1							
Nepeta hispanica subsp. *hispanica*	0				1	EX		2006	0
Nepeta rtanjensis	0				1	CR	B2c	2006	1
Nepeta sphaciotica	2	1			1	CR	B1+3c ; E	2006	0
Nigella degenii subsp. *minor*	0				1	CR	D	2006	1
Notothylas orbicularis	3	1							
Odontites granatensis	3	1			1	CR	A2abde ; B1ab (III,V) + 2ab (III,V)	2006	1
Oenanthe conioides	25	1			1	CR	A1ac, B1+2c	2006	1
Omphalodes kuzinskyana	1				1	CR	B1+2ade	2006	2
Omphalodes kuzinskyanae	0	1							
Omphalodes littoralis	99	1							
Onobrychis peloponnesiaca	0				1	CR	B1+2c	2006	0
Ononis azcaratei	7				1	CR	B1ab II,III,IV,V)+2ab(I,II,III,IV,V)	2006	0
Ononis hackelii	3								
Ononis maweana	3	1							
Onopordum eriocephalum	1				1	CR	A1a,c	2006	1
Onosma arenaria subsp. *pyramidata*	0				1	CR	A1a,c; C1	2006	1
Onosma austriaca	0				1	CR		2006	0
Onosma fastigiata subsp. *atlantica*	0				1	CR	A1ac, D	2006	1

Onosma graniticola	0		1	CR		2006	0
Onosma halophilum	2	1					
Onosma polyphylla	1	1					
Onosma proponticum	0	1	1	CR	A2cd, E	2004	0
Onosma sangiasense	0		1	CR	B1+2c	2006	0
Onosma stridii	0		1	CR	B1+3c	2006	0
Onosma tornensis	2	1	1	CR	B1+2c	2006	2
Onosma troodi	1	1					
Ophioglossum polyphyllum	17	1					
Ophrys argolica	0	1					
Ophrys celiensis	0		1	CR	B1+2c	2006	0
Ophrys isaura	0	1					
Ophrys kotschyi	1	1					
Ophrys lunulata	3	1					
Ophrys lycia	0	1					
Ophrys oestrifera	3	1					
Ophrys taurica	0	1					
Orchis nervulosa	0		1	CR		2004	0
Orchis provincialis	32	1					
Orchis punctulata	10	1					
Origanum cordifolium	2	1					
Origanum dictamnus	16	1					
Origanum scabrum	10	1					
Origanum symes	2		1	CR	B1+2c	2006	0
Ornithogalum reverchonii	4	1					
Orthothecium lapponicum	23						
Orthotrichum rogeri	134	1					
Oxytropis deflexa subsp. *norvegica*	0	1					
Oxytropis javalambrensis	0		1	CR	B2ac(III,IV)	2006	1
Oxytropis kozhuharovii	0		1	CR	B1+3e	2006	0
Paeonia cambessedesii	11	1					
Paeonia clusii subsp. *rhodia*	0	1					
Paeonia officinalis subsp. *banatica*	0	1					

Paeonia parnassica	2	1						
Paeonia tenuifolia	5	1						
Palaeocyanus crassifolius	0	1						
Papaver laestadianum	2							
Papaver lapponicum	409	1						
Papaver radicatum subsp. *hyperboreum*	0							
Paronychia bornmuelleri	1			1	EX		2006	0
Pastinaca sativa subsp. *fleischmannii*	0			1	EW		2006	1
Pedicularis sudetica	221	1						
Persicaria foliosa	57							
Petagnaea gussonei	0			1	CR	B1+B2c	2006	2
Petagnia saniculifolia	0	1						
Petalophyllum ralfsii	261	1						
Petrocoptis grandiflora	17	1						
Petrocoptis montsicciana	2	1						
Petrocoptis pseudoviscosa	1	1						
Peucedanum kyriakae	0			1	CR	B1a + 2a + c1	2006	0
Peucedanum nebrodense	0			1	CR	B1+2c	2006	1
Peucedanum officinale subsp. *brachyradium*	0			1	CR	B1ab (III,V) + 2ab (III,V) ; C2a (I,II) ; D	2006	0
Phagnalon metlesicsii	0			1	CR	B1+2c	2006	0
Phleum sardoum	0			1	CR	B1+2c	2006	1
Phlomis brevibracteata	0	1						
Phlomis cypria	0	1						
Phlomis x margaritae	0			1	CR	B1ab(III)+2ab(III);C2a(I,II);D	2006	1
Phoenix theophrasti	5	1	LR/nt					
Physoplexis comosa	47	1						
Picris willkommii	5	1						
Pilularia minuta	15	1						
Pinguicula bohemica	0			1	CR	A1a	2006	1
Pinguicula crystallina	1	1						
Pinguicula nevadensis	11	1						

Pinguicula poldinii	1			1	CR	E	2004	2
Pirinia koenigii	0			1	CR	D	2006	0
Plagiomnium drummondii	102							
Plantago algarbiensis	1			1	CR	D	2006	1
Plantago almogravensis	2			1	CR	D	2006	1
Plantago atrata subsp. *sudetica*	0			1	CR	B1+2c	2006	0
Platanthera obtusata subsp. *oligantha*	0	1	* Substantial data are available for the species					
Poa granitica	1	1						
Poa langeana	0			1	EX		2006	0
Poa margillicola	0			1	CR	B1+2c	2006	0
Poa riphaea	0	1		1	CR	D	2006	1
Poa sejuncta	0			1	CR		2004	0
Polemonium boreale	199	1						
Polygala apiculata	0			1	CR	B1ab(iv)	2006	1
Polygala helenae	0			1	CR	B1ab (III) +2ab (III)	2006	0
Polygala pisaurensis	2			1	CR	E	2004	0
Polygala sinisica	0			1	CR	B1ab (II) +2ab (II)	2006	0
Polygonum praelongum	0	1						
Posidonia oceanica	405	1						
Potentilla collina	238			1	EX		2006	0
Potentilla delphinensis	51	1						
Potentilla emilii-popii	0	1						
Potentilla praecox	3			1	CR	A4d, B1+2c	2006	0
Potentilla rhenana	6			1	CR	B1+2c	2006	0
Potentilla silesiaca	0	1						
Potentilla volgarica	0			1	EX		2006	0
Potentilla wimanniana	0			1	CR		2006	0
Potentilla wismariensis	0			1	CR		2006	1
Primula apennina	2	1						
Primula deorum	2	1						
Primula egaliksensis	150	1						
Primula frondosa	0	1						

Primula glaucescens	2	1						
Primula nutans	270							
Primula palinuri	4	1						
Primula scandinavica	1349							
Primula spectabilis	4	1						
Primula wulfeniana	1	1						
Primula wulfenianum subsp. *baumgarteniana*	0			1	EW		2006	4
Pseudarrhenatherum pallens	0			1	CR	D, E	2006	0
Pseudomisopates rivas-martinezii	4			1	CR	B1ab (III)+2ab (III) ; C2a(II)	2004	1
Ptilophora mediterranea	0	1						
Puccinellia gussonei	0			1	EX		2006	0
Puccinellia pannonica	0			1	EX		2006	0
Puccinellia phryganodes	284							
Puccinellia pungens	5	1						
Pulsatilla grandis	18	1						
Pulsatilla oenipontana	3			1	CR	A1ac, B1+2c, C1	2006	0
Pulsatilla patens	484	1						
Pulsatilla pratensis subsp. *hungarica*	0			1	CR	B2c+3c	2006	1
Pulsatilla slavica	4	1						
Pulsatilla vulgaris subsp. *gotlandica*	0							
Pyramidula tetragona	17	1						
Pyrus anatolica	0	1	LR/nt					
Pyrus magyarica	0			1	CR	D	2006	0
Quercus mestensis	0			1	CR	B1+2c	2006	0
Ramonda serbica	2	1						
Ranunculus altitatrensis	0			1	CR	B1+2c	2006	1
Ranunculus elisae	0			1	CR	D	2006	0
Ranunculus fontanus	3	1						
Ranunculus kykkoensis	2	1						
Ranunculus lapponicus	381							
Ranunculus montserratii	1			1	CR	B1ab (IV,V) + 2ab (IV,V) ; C2a (II)	2006	0
Ranunculus radinotrichus	2			1	CR	B2c+3c	2006	0

Ranunculus stojanovii	0				1	CR	B2c+3c	2006	0
Ranunculus sylviae	0				1	CR	D	2006	0
Ranunculus veronicae	0				1	CR	D	2006	1
Ranunculus weyleri	8	1							
Reseda decursiva	39	1							
Rhamnus lojaconoi	0				1	CR	B1+2d	2006	0
Rhamnus persicifolius	0				1	CR	D	2004	1
Rhazya orientalis	2	1			1	CR	A1bc, B1+2c	2006	3
Rheum rhaponticum	54	1							
Rhinanthus cretaceus	0				1	CR		2004	0
Rhynchosinapis erucastrum subsp. *cintrana*	0								
Ribes sardoum	0	1	CR	B1ab(v)+2ab(v)	1	CR	B1ab (V) + (V)	2006	1
Riccia breidleri	7	1							
Riella helicophylla	20	1							
Romulea limbarae	0				1	CR	B1+2c	2006	1
Rorippa valdes-bermejoi	1				1	CR	B1ab(I,II,III,IV,V)+2ab(I,II,III,IV,V);C1+2a(II)b	2006	1
Rosa donetzica	0				1	CR		2006	1
Rosmarinus tomentosus	27	1							
Rouya polygama	6	1							
Rubia balearica subsp. *caespitosa*	0				1	CR	B1ab(IV)+2ab(IV)	2004	1
Rumex rupestris	480	1							
Rupicapnos africana	63	1							
Sagina boydii	0				1	EW		2006	3
Salicornia heterantha	0				1	CR		2006	0
Salicornia veneta	4	1							
Salix hastata subsp. *picoeuropeana*	0				1	CR	D2	2006	1
Salix hastata subsp. *sierrae-nevadae*	0				1	CR	B1ab (III) + 2ab (III) ; C2a (I) ; D	2006	1
Salix salvifolia subsp. *australis*	0								
Salsola anatolica	0	1							
Salvia ceratophylloides	0				1	CR	A1a,c	2006	1
Salvia crassifolia	0	1							
Salvia desoleana	0				1	CR	D	2004	2

Salvia tingitana	1				1	EW		2006	3
Salvia veneris	0				1	CR	B1ac (IV)	2004	0
Salvinia natans	252	1							
Santolina elegans	11	1							
Santolina impressa	3								
Santolina melidensis	7				1	CR	B1ab(II,III,V)+2ab(II,III,V)	2006	1
Santolina semidentata	11								
Saponaria halophila	2	1							
Saponaria jagelii	0				1	CR	B1ab (I,II,III,V) + B2ab (I,II,III,V)	2006	1
Satureja acropolitana	0				1	EX		2006	0
Saussurea porcii	0				1	CR		2006	0
Saxifraga berica	0	1							
Saxifraga cintrana	0	1							
Saxifraga florulenta	0	1							
Saxifraga hirculus	2250	1							
Saxifraga oppositifolia subsp. *amphibia*	0				1	EX		2006	0
Saxifraga osloënsis	0								
Saxifraga presolanensis	1	1							
Saxifraga rosacea subsp. *hartii*	0				1	CR	B1+2c, D	2006	2
Saxifraga tombeanensis	4	1							
Saxifraga valdensis	23	1							
Saxifraga vayredana	7	1							
Scabiosa achaeta	0				1	EX		2006	0
Scapania massalongi	10	1							
Schimmelmannia schousboei	0	1							
Schivereckia podolica	3	1							
Scilla dimartinoi	0				1	CR	B1+2c	2006	1
Scilla morrisii	0	1	CR	B1ab(i,ii,iii)+2ab(i,ii,iii)	1	CR	B1ab (I,II,III) + 2ab II,III)	2006	2
Scilla odorata	6	1							
Scrophularia exilis	0				1	CR		2004	0
Scrophularia viciosoi	21				1	CR	B1 + 2c	2006	1
Sedum annuum subsp. *gussonei*	0				1	CR	E	2004	0

Sedum borissovae	0			1	CR		2004	2
Sedum villosum var. pentandrum	0			1	CR	A1;B2ab(i,ii,iii,iv,v);E	2006	1
Sempervivum pittonii	2			1	CR	B1+2c	2006	3
Senecio alboranicus	1			1	CR	B1ab(III,V)c(IV)+2ab(III,V) C(IV)	2006	1
Senecio elodes	6	1						
Senecio jacobea subsp. *gotlandicus*	0							
Senecio nevadensis	5	1						
Serratula tanaitica	0	1						
Seseli djianeae	0			1	CR	A2a,c	2004	0
Seseli intricatum	4	1						
Sesleria tuzsonii	0			1	EX		2006	0
Sideritis cypria	0	1						
Sideritis incana subsp. *glauca*	0	1						
Sideritis javalambrensis	5	1						
Sideritis serrata	5	1		1	CR	B2ab (II)	2006	1
Silene ammophila subsp. *ammophila*	0			1	CR	B1+2c	2006	0
Silene astrachanica	0			1	CR		2006	0
Silene cephallenia subsp. *cephallenia*	0			1	CR	B1+2c(iv)	2006	0
Silene conglomeratica	0			1	CR	A1c	2006	0
Silene cretacea	0	1						
Silene dirphya	1			1	CR	B1+2c	2006	0
Silene furcata subsp. *angustiflora*	0	1						
Silene gazulensis	1			1	CR	B1ab (III,V)+2ab(III,IV), C2a(II)	2006	1
Silene guicciardii	0			1	EX		2006	0
Silene haussknechtii	8	1						
Silene hicesiae	0			1	CR	B1ab (IV,V) + 2ab (IV,V)	2006	1
Silene hifacensis	35	1						
Silene holzmanii	3							
Silene hypanica	0			1	CR		2004	1
Silene ichnusae	0			1	CR	D	2004	0
Silene integripetala subsp. *elaphonesiaca*	0			1	CR	B1+2c	2006	0
Silene integripetala subsp. *lidenii*	0			1	CR	A1c	2006	0

Silene jailensis	0			1	CR		2004	0
Silene linicola	48			1	EW	A1abcde, E	2006	2
Silene longicilia	2							
Silene mariana	16	1						
Silene nikolicii	0			1	CR		2006	0
Silene orphanidis	3	1						
Silene pompeiopolitana	0	1						
Silene rothmaleri	3	1						
Silene salsuginea	2	1						
Silene sanctae-therasiae	0			1	CR	D; E	2004	0
Silene sangaria	2	1						
Silene stockenii	3			1	CR	B1b II,III,IV,V) c (IV)+2b(I,II,III,IV,V); C (IV)	2006	1
Silene taygetea	2			1	CR	B1+2c	2006	0
Silene uniflora subsp. *cratericola*	0			1	CR	B1+2c	2006	1
Silene velutina	15	1						
Sisymbrium cavanillesianum	10	1						
Sisymbrium confertum	0	1						
Sisymbrium supinum	804	1						
Soldanella villosa	46	1						
Solenanthus albanicus	3	1						
Solenanthus krasniqii	0			1	CR	B1+2ce, C2ab, D	2006	0
Solenanthus reverchonii	1			1	CR	C2b, D	2006	1
Sonchus erzincanicus	0	1						
Sorbus leyana	32			1	CR	B1+2c, D	2006	1
Sorbus parumlobata	9			1	CR	D	2006	0
Sorbus teodori	58							
Sorbus wilmottiana	16			1	CR	B1+2c, D	2006	2
Sphaerophysa kotschyana	2	1						
Sphagnum pylaisii	10	1						
Spiraea media subsp. *polonica*	0			1	CR		2006	0
Spiranthes aestivalis	1920	1						
Stachys aimerici	0			1	CR	B1	2006	0
Stachys albanica	0			1	EX		2006	0

Stachys spreintzenhoferi subsp. *virella*	0			1	CR	B1+2c, C2ab, D	2006	0
Sternbergia candida	0	1						
Steveniella satyrioides	0	1						
Stipa adoxa	0			1	CR		2004	1
Stipa austroitalica	6	1						
Stipa bavarica	0	1						
Stipa danubialis	0	1		1	CR		2006	0
Stipa fallacina	0			1	CR		2004	0
Stipa majalis	0			1	CR		2006	0
Stipa pulcherrima subsp. *bavarica*	0			1	CR	B1+2c	2006	4
Stipa styriaca	20	1		1	CR	A1c, B1+2c	2006	0
Stipa syreistschikowii	0	1						
Stipa veneta	0							
Suaeda cucullata	0	1						
Suaeda pelagica	0			1	CR	B1+2c	2006	0
Suaeda pruinosa var. kochii	0			1	EX		2006	0
Succisa pinnatifida	7			1	CR	B2ab (II,IV,V)	2006	0
Symphytum cycladense	2	1						
Syringa josikaea	51	1						
Tanacetum funkii	0			1	EX		2006	0
Taraxacum caramanicae	0			1	CR	B1+2c	2006	0
Taraxacum decrepitum	0			1	CR	B1+2c	2006	0
Taraxacum gaditanum	1			1	CR	B1ab (II,III,IV,V)+2ab(I,II,III,IV,V)	2006	1
Taraxacum iberanthum	2			1	CR	B2ab (I,II,III)	2006	0
Taraxacum pieninicum	0			1	CR	D	2006	1
Taraxacum solenanthinum	1			1	CR	B2ac (II,III)	2006	0
Taraxacum stenospermum	1			1	CR	D	2006	0
Taraxacum vinosum	1			1	CR	B1ab(I,II,III,IV,V) + (I,II,III,IV,V)	2006	0
Tayloria rudolphiana	5	1						
Teline tribracteolata	11			1	CR	B2ab(I,II,III,IV,V)	2006	0
Tephroseris integrifolia subsp. *serpentini*	0			1	CR	A1c	2006	0
Tephroseris integrifolia subsp.	0			1	CR	A1c	2006	0

vindelicorum								
Tephroseris longifolia subsp. *moravica*	0		1	CR		2006	1
Teucrium charidemi	26	1					
Teucrium cravense	1		1	CR	B1	2006	1
Teucrium lamiifolium	0	1					
Teucrium lepicephalum	57	1					
Teucrium turredanum	15	1					
Thermopsis turcica	0	1					
Thesium ebracteatum	134	1					
Thesium vlachorum	1		1	CR	B1+2c	2006	0
Thlaspi cariense	0	1					
Thlaspi jankae	4	1					
Thorella verticillatinundata	11	1					
Thymelea broterana	0	1					
Thymus aznavourii	0	1	1	CR		2006	0
Thymus camphoratus	11	1					
Thymus carnosus	21	1					
Thymus cephalotos	3	1					
Thymus herba-barona subsp. *bivalens*	0		1	CR	B1ab(III,V)+2ab(III,V) ; C2a(II)	2006	1
Thymus hyemalis subsp. *millefloris*	0		1	CR	B1ab (III,V) + 2ab(III,V)	2006	0
Thymus lotocephalus	0						
Thymus oehmianus	0		1	CR		2006	0
Thymus webbianus	16		1	CR	B1ab(III)+2ab(III)	2006	0
Tortella rigens	7						
Trachelium asperuloides	0	1					
Trachomitum venetum subsp. *tauricum*	0		1	CR	D	2004	0
Tragopogon pseudocastellanus	2		1	CR	A2c ; B2ab(I,II,V) ; D	2006	1
Trapa annosa	0		1	EX		2006	0
Trapa natans	985	1					
Trichomanes speciosum	1137	1					
Trifolium banaticum	0	1					

Trifolium barbeyi	0		1	CR	A1c	2006	0
Trifolium pachycalyx	0	1					
Trifolium saxatile	48	1					
Trifolium uniflorum subsp. *savianum*	0		1	CR	A1c	2006	0
Trigonella arenicola	2	1					
Trigonella halophila	0	1					
Trigonella polycarpa	0	1					
Trisetum subalpestre	59	1					
Tuberaria major	2	1					
Tulipa aximensis	0		1	CR	A1ac, D	2006	2
Tulipa billietiana	0		1	EW		2006	1
Tulipa cypria	0	1					
Tulipa didieri	1		1	CR	A1ac, C1	2006	3
Tulipa goulimyi	2	1					
Tulipa grengiolensis	0		1	CR	A4d, C2a, E	2006	2
Tulipa hungarica	0	1					
Tulipa lortetii	1		1	CR	A1ac	2006	1
Tulipa marjoletii	0		1	EW		2006	3
Tulipa mauriana	1		1	CR	A1ac	2006	3
Tulipa montisandrei	0		1	CR	A1ac, D	2006	1
Tulipa planifolia	1		1	EW		2006	2
Tulipa platystigma	3		1	CR	B1+2c, D	2006	1
Tulipa praecox	21	1					
Tulipa scythica	0		1	CR		2006	1
Tulipa serbica	0		1	CR	B2c	2006	1
Tulipa sprengeri	1	1					
Typha minima	45	1					
Typha shuttleworthii	14	1					
Vaccinium arctostaphylos	6	1					
Valantia calva	0		1	CR	C2a, D	2004	0
Valerianella falconida	0		1	CR		2004	0
Verbascum afyonense	0	1					
Verbascum basivelatum	0	1					

Verbascum charidemi	4		1	CR	B1ab(II,III,IV,V)c(III,IV)+2ab(II,III,IV,V)c(III,IV); C2a(I)b	2004	1
Verbascum cylleneum	1	1					
Verbascum degenii	0	1	1	CR		2006	0
Verbascum litigiosum	2						
Verbascum purpureum	0	1					
Verbascum stepporum	0	1					
Veronica chamaepithyoides	1		1	CR	B1ab(II,IV)c(IV)+2ab(II,IV)c(IV);C2a(I)b; D; E	2006	0
Veronica dabneyi	1		1	CR	A2b; C	2006	1
Veronica euxina	0	1	1	CR	B1+2abcd	2006	0
Veronica micrantha	12						
Veronica oetaea	5	1	1	CR	B1+2c	2006	0
Veronica tenuifolia subsp. *fontqueri*	0		1	CR	B2b(IV) ; C(IV)	2004	0
Veronica turrilliana	0	1					
Vicia bifoliolata	2	1	1	CR	B1ab(IV)+2ac(IV), D	2006	1
Vicia davisii	0		1	CR	B1+2c	2006	0
Vicia dennesiana	0		1	EX		2006	0
Vicia giacominiana	0		1	CR	B1+2c	2006	0
Vincetoxicum pannonicum	0	1	1	CR		2006	1
Viola allchariensis subsp. *allchariensis*	0		1	CR	D	2006	4
Viola arsenica	0		1	CR	B1+2a, D	2006	0
Viola athois	2	1					
Viola cazorlensis	28	1					
Viola cryana	19	1	1	EX		2006	0
Viola delphinantha	9	1					
Viola hispida	43	1	1	CR	A1a	2006	2
Viola jaubertiana	5	1					
Viola pseudomirabilis	1		1	CR	A1a,c; C1	2004	0
Viola rupestris subsp. *relicta*	0						
Viola ucriana	0		1	CR	B1ab ,III,V) + 2ab (II,III,V)	2006	1
Wagenitzia lancifolia	0	1					
Woodwardia radicans	157	1					
Wulfenia baldaccii	1		1	EW		2006	3

Zelkova abelicea	11	1	VU	B1+2ce, D2					
Zelkova sicula	0				1	CR	B1ab(I,II,V) + 2ab (I,II,V) ; C2a (II)	2006	1
Zostera marina	3484	1							
Total	52109	542			619	619			