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Sensitivity of Dutch vascular plants to climate change and habitat fragmentation

A preliminary assessment based on plant traits in relation to past trends and future projections

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Abstract

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In the present study indicators were developed for the sensitivity of plant species to climate change and habitat fragmentation, by analysing large databases. The resulting sensitivity scores were confronted with trends observed over the 20th century in the frequency of occurrence of species. The scores for sensitivity to climate change and habitat fragmentation can both explain part of the trends observed over the 20th century. Within the group of species that are sensitive to climate change, the highest proportion of deteriorating species was found among the subset of species with low dispersal ability. This supports the theory that the effects of climate change on biodiversity are aggravated by habitat fragmentation.

Keywords: climate change, habitat fragmentation, range characteristics, dispersal ability, sensitivity scores, trends

Referaat

Ozinga, W.A., M. Bakkenes & J.H.J. Schaminée, 2007. *Gevoeligheid van Nederlandse vaatplanten voor klimaatverandering en habitatversnippering – Een inschatting op basis van functionele kenmerken in relatie tot trends en voorspellingen.* Wageningen, Wettelijke Onderzoekstaken Natuur & Milieu. WOt-rapport 49. 46 pp. 15 fig.; 8 tab.; 103 ref.

In dit project zijn kentallen ontwikkeld voor de gevoeligheid van plantensoorten voor habitatversnippering en klimaatverandering door het analyseren van omvangrijke gegevensbestanden. Deze kentallen zijn geconfronteerd met trends in de mate van voorkomen. De kentallen voor de gevoeligheid voor versnippering en de kentallen voor gevoeligheid voor klimaatverandering kunnen een deel van de waargenomen trends over de 20e eeuw verklaren. Binnen de groep soorten met een hoge gevoeligheid voor klimaatverandering is het aandeel afnemende soorten het hoogst voor soorten met hoge gevoeligheid voor versnippering (soorten met een geringe dispersiecapaciteit). Dit resultaat ondersteunt de theorie dat effecten van klimaatverandering op biodiversiteit worden uitvergroot door fragmentatie.

Trefwoorden: klimaatverandering, habitatversnippering, areaalkarakteristieken, dispersiecapaciteit, kentallen, trends

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Summary

Climate change is regarded as one of the major pressures on biological diversity, and its possible effects are receiving increasing attention in the European Union's policy. However, its possible consequences for plant species and ecosystems are insufficiently known. The effects of climate change might be reinforced by the effects of habitat fragmentation. In the present study, indicators were developed for sensitivity to climate change and habitat fragmentation. The resulting sensitivity scores were confronted with trends in the frequency of occurrence observed over the 20th century.

The possible response to climate change was studied by two approaches: an existing regression model covering 20% of the European vascular plant species (EuroMove) was complemented with an approach based on the characteristics of geographical ranges of plant species (size of the range and position of the Netherlands within the range).

The results demonstrate that it is feasible to assign climate change and habitat fragmentation sensitivity scores to vascular plant species for the purpose of risk assessment studies. There was a close correspondence between the results produced by EuroMove and the results based on range characteristics. The climate change and habitat fragmentation sensitivity scores both explain part of the observed trends.

Within the group of species that are sensitive to climate change, the highest proportion of deteriorating species was found among the subset of species with low dispersal ability. This supports the theory that the effects of climate change on biodiversity are aggravated by habitat fragmentation.

The number of southern species that might benefit from climate change is relatively large in comparison to the number of northern and submontane species that are at risk. Species numbers alone are therefore not a good indicator of the effects of climate change on vascular plants.

The current mechanistic understanding of the effects of both climate change and habitat fragmentation on local species composition is poor, and it should be stressed that the sensitivity scores developed in the present study are meant to explore risks rather than to give precise predictions. Urbanisation might provide an alternative explanation for at least part of the observed trends. The unravelling of the effects of climate change, habitat fragmentation and urbanisation requires a more detailed, spatially explicit and habitat-specific analysis.

Samenvatting

De mogelijke effecten van klimaatveranderingen krijgen binnen het beleid van de Europese Unie in toenemende mate aandacht. Er bestaat echter nog veel onduidelijkheid over de ruimtelijke consequenties van klimaatveranderingen voor soorten en levensgemeenschappen. In dit project zijn kentallen ontwikkeld voor de gevoeligheid van plantensoorten voor versnippering en klimaatverandering door het analyseren van omvangrijke, digitaal beschikbare gegevensbestanden. Deze kentallen zijn geconfronteerd met trends in de mate van voorkomen. De resultaten geven inzicht in de mate waarin klimaatverandering in relatie tot dispersie verantwoordelijk is voor recent waargenomen veranderingen in biodiversiteit.

Om de gevoeligheid voor klimaatverandering te schatten, zijn twee methodes gebruikt: een bestaand regressiemodel voor 20% van de Europese vaatplanten (EuroMove) is aangevuld met een risico-inschatting op basis van karakteristieken van het geografisch areaal (grootte van het areaal en ligging van Nederland ten opzichte van de rest van het areaal).

De resultaten tonen dat er een goede overeenkomst is tussen de binnen dit project ontwikkelde kentallen en de risico-inschatting op basis van EuroMove. De kentallen voor de gevoeligheid voor versnippering en de kentallen voor gevoeligheid voor klimaatverandering kunnen een deel van de waargenomen trends over de 20^{e} eeuw verklaren.

Binnen de groep soorten met een hoge gevoeligheid voor klimaatverandering is het aandeel afnemende soorten het hoogst voor soorten met hoge gevoeligheid voor versnippering (soorten met een geringe dispersiecapaciteit). Dit resultaat ondersteunt de theorie dat effecten van klimaatverandering op biodiversiteit worden uitvergroot door fragmentatie.

Het aandeel zuidelijke soorten die kunnen profiteren van een temperatuurstijging is relatief groot in vergelijking met het aantal noordelijke en submontane soorten die gevoelig zijn voor temperatuurstijging. Soortenaantallen alleen zijn daarom geen goede indicator voor effecten van klimaatverandering op vaatplanten.

Voor een beter begrip van de mechanismen achter de waargenomen trends bij vaatplanten is het wenselijk om een gedetailleerde analyse uit te voeren per habitattype. Op deze manier kunnen alternatieve verklaringen, zoals urbanisatie, beter onderscheiden worden van effecten van klimaatverandering en versnippering.

1 Introduction

1.1 Project description

Background

Climate change is considered globally one of the major pressures on biological diversity (Millennium Ecosystem Assessment 2005) and their possible effects are receiving increasingly attention in the European Union's policy (Delbaere 2005; Duke 2005). The possible consequences for plant species and vegetations are however insufficiently known. These uncertainties in possible effects may hamper the evaluation of cost-effective policy scenarios at both the national and the European level. For biodiversity policy there is therefore a growing need for simple 'sensitivity scores' that describe the sensitivity of individual species to various environmental pressures (Wiertz 2005, De Heer et al., 2005).

At the Netherlands Environmental Assessment Agency a climate response model (EuroMove) was developed by Bakkenes et al. (2002). EuroMove is a niche-based species distribution model that relates observations of almost 1,400 European vascular plant species to various climate characteristics. Using multiple logistic regression equations, the occurrence probabilities across Europe are calculated for this subset of European vascular plant species and subsequently the model projects fitted 'climatic envelopes' to future climate scenarios.

Since EuroMove contains information for only 20% of the European plant species, it would be worthwhile to consider additional information that might be of importance for the response of plant species to climate change, such as size and the position of geographical ranges. Regional extinction risk is expected to be the highest for species with small ranges and for species where the area of interest (i.e. the Netherlands) is at the southern border of their distribution area.

Existing climate response models, including EuroMove, do in general not include information on the dispersal ability of plant species. An important question in this respect is the degree to which plant species can track changes in spatial configuration of suitable habitats as a consequence of climate change. For some species the required migration rates might exceed their dispersal ability. This problem might be reinforced by the effects of habitat fragmentation. From recent studies in the Netherlands it became apparent that the degree to which plants can track suitable habitat conditions is strongly affected by their dispersal ability (Ozinga et al., 2005a, 2005b). In the present project the research on climate change effects on vascular plants will be broadened by including information on seed dispersal.

Aim

The present project aims at the development of sensitivity scores for individual plant species for climate change and for habitat fragmentation. These sensitivity scores may increase our insight in the possible effects of climate change, habitat fragmentation and their interaction on the occurrence of plant species in the Netherlands. These sensitivity scores can therefore be helpful in comparing policy scenarios for their possible effects on biodiversity. The sensitivity scores will become available in the EU-FP6 project BioScore (see par. *Related projects*).

Since responses of plant species to climate change and habitat fragmentation are both very complicated, this project only aims at a first scan of patterns for the Netherlands. By combining these sensitivity scores to observed trends we try to find indications to what extent climate change is already responsible for changes in plant occurrences.

Research questions

The following research questions will be addressed in this project:

- Is it possible to derive species specific indicators for sensitivity for climate change and habitat fragmentation for usage in nature policy?
- What are the changes in frequency of occurrence of plant species in the Netherlands based on available monitoring data?
- What is the possible role of climate change and habitat fragmentation in explaining these changes?

Related projects

WOT projects

The present project is related to several other 'WOT projects' from the Statutory Research Tasks Unit for Nature and the Environment (*WOT Natuur & Milieu*) in which aspects of climate change and dispersal are addressed. Especially relevant are the following projects:

- WOT 8.1 – Selection of plant and animal species for which the Netherlands have a high international responsibility (Janssen et al., 2007);
- WOT 8.3 – Development of a dispersal model (Wamelink et al., in prep.);
- WOT 8.4 – Climate change effects at the landscape level (Corporaal et al., 2007).

Furthermore, the sensitivity scores that will be developed in the present WOT project may be useful for two international projects in which the Netherlands Environmental Assessment Agency (MNP) is involved: BioScore and Globio.

BioScore

The sensitivity scores that will be developed in the present WOT project will be fed into the BioScore project (Project Leader: Ben Delbaere, ECNC). BioScore is a research project under the EU Commission's Sixth Framework Programme with a time frame from 2006 till 2008. Biodiversity indicators and monitoring frameworks are currently developed at the European and global level. A key tool for monitoring progress in achieving the EU target to halt the loss of biodiversity by 2010 is the recently endorsed set of EU headline biodiversity indicators. A requirement by the EU is to complement the indicator set and the development of biodiversity monitoring frameworks with tools that are able to assess the impacts of Community policies on biodiversity in a cost-effective way.

The BioScore project will satisfy this requirement by developing a tool for linking pressures from policy sectors to the (change in the) state of biodiversity as measured by the presence and abundance of individual species. The tool to be developed will be a database that will contain information on the ecological preferences of individual species in relation to individual sectoral pressures and relating to selected Community policies as well as the EU headline biodiversity indicators. This tool will be applied for assessing impacts and the effectiveness of biodiversity conservation policies based on historic data as well as for forecasting future impacts based on existing scenario studies. The results of these assessments will be presented in European maps.

GLOBIO

The Netherlands Environmental Assessment Agency (MNP) is involved in exploring candidate policy options which could contribute towards the achievement of the 2010 biodiversity target at global level. These assessments are carried out using a chain of models that allow a quantitative approach (Alkemade et al., 2006, Ten Brink et al 2006, MNP 2006). On the global scale, the results of macroeconomic, demographic projections and an agricultural trade model (GTAP: Global Trade Analysis Project) and a global integrated environmental assessment model (IMAGE: Integrated Model to Assess the Global Environment) are fed into a global biodiversity assessment model (GLOBIO). These models work within the conceptual framework used in the Millennium Ecosystem Assessment (2003, 2005), where indirect drivers like population, economy, technology and lifestyle are used to determine direct drivers of change, such as land-use change (agriculture and forestry), climate change, nitrogen-deposition and fertiliser use. These direct drivers affect ecosystems and biodiversity. Changes in ecosystem goods and services in turn affect human well-being. Two important issues that meet in the current project are climate change and biodiversity. An improved understanding of the sensitivity of plant species to climate change, urbanisation and habitat fragmentation can be useful for the performance of scenario analysis at the European level.

1.2 Climate change

Climate is among the major factors that determine the limits to the geographical distribution of species. The influence of climate on plant performance is both indirectly through its effects on habitat conditions and man-induced changes in the landscape as a response to climate change, and more directly through its inference with plant physiology (see § 1.3). Climate can be defined as the weather conditions in an area over a long period of time (normally 30 years) and is described using statistical information based on meteorological observations (past climate) or based on climate models using data from past climates and global change scenarios (future projections). Some climate terminology is given in box 1.

Box 1: Climate terminology (based on Dahl 1998, Moen 1999).

Temperature
Temperature is the mean value of the temperature over a given period of time. From the plant's perspective the temperature of the warmest month and the temperature of the coldest month are most relevant.

Precipitation
Precipitation is the sum of rain, sleet, snow and dew that has fallen during a given period of time.

Humidity
Atmospheric humidity is determined by both the amount of water vapour in the air and air temperature. Warm air can retain much more water vapour than cold air. Areas with high humidity occur where the air temperature, amount of precipitation and frequency of precipitation are high. For plants atmospheric humidity is of great importance because it influences, among other things, the evapotranspiration from the leaves and the moisture in the soil. Humidity can be expressed by a 'moisture index' which gives the ratio between actual and potential evapotranspiration.

Evapotranspiration
Water loss from an area to the atmosphere as a result of losses from soil and surface-water bodies (evaporation) and losses from plants (transpiration). Drought stress occurs when evapotranspiration exceeds the available amount of water stored in the soil or falling as rain.

Oceanic climate
The climate near the continental coast, characterized by the influence of the sea. Winters are mild, summers cool, atmospheric humidity is high and precipitation is fairly evenly distributed through the year.

Continental climate
The climate in inland regions, characterized by dry, cold winters and warm summers with rain showers. The total annual precipitation and atmospheric humidity are relatively low.

Past trends

An increasing body of observations gives a collective picture of a warming world and other changes in the climate system (IPCC 2001, 2007). Figure 1 gives an overview of the variations of the Earth's surface temperature over the last 140 years (upper pane) and the last millennium (lower pane). In the upper pane the Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (red line, a filtered curve suppressing fluctuations below near decadal time-scales). The uncertainties in the data are illustrated with grey bars representing the 95% confidence range). The 20th century experienced the strongest warming trend of the last millennium with average surface temperatures rising by about 0.6°± 0.2 C (Jones 2001, IPCC 2001). In the lower pane the year by year (light blue curve) and 50 year average (dark purple curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from 'proxy' data calibrated against thermometer data. The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium (IPCC 2001).

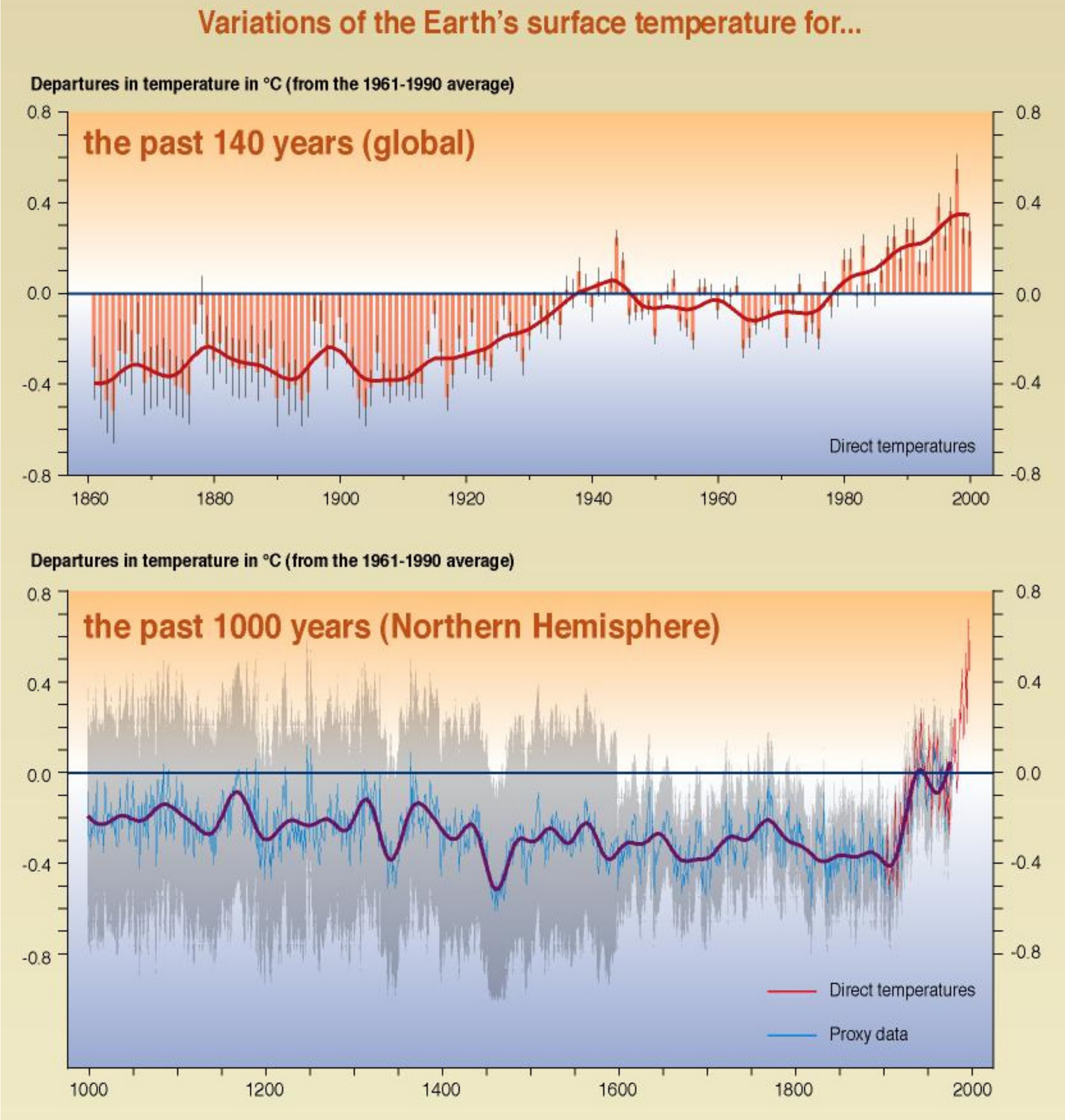

Figure 1: Global temperature change in the period 1861-2000 (upper pane) and 1000-2000 (lower pane; taken from IPCC 2001).

Future projections

Climate change scenarios at the global scale

The projection of future climate change depends partly on the assumptions made about trends in the main driving forces (population and economic growth), and environmental pressures (emissions from energy, industrial and land use) and their resulting effects, such as temperature increase (IPCC 2001, Van Vuuren et al., 2003). An overview of the effects of six climate change scenarios on the global temperature is given in Figure 2. For further details on climate change scenarios we refer to IPCC (2001), Van Vuuren et al., (2003) and Bakkenes et al., (2006).

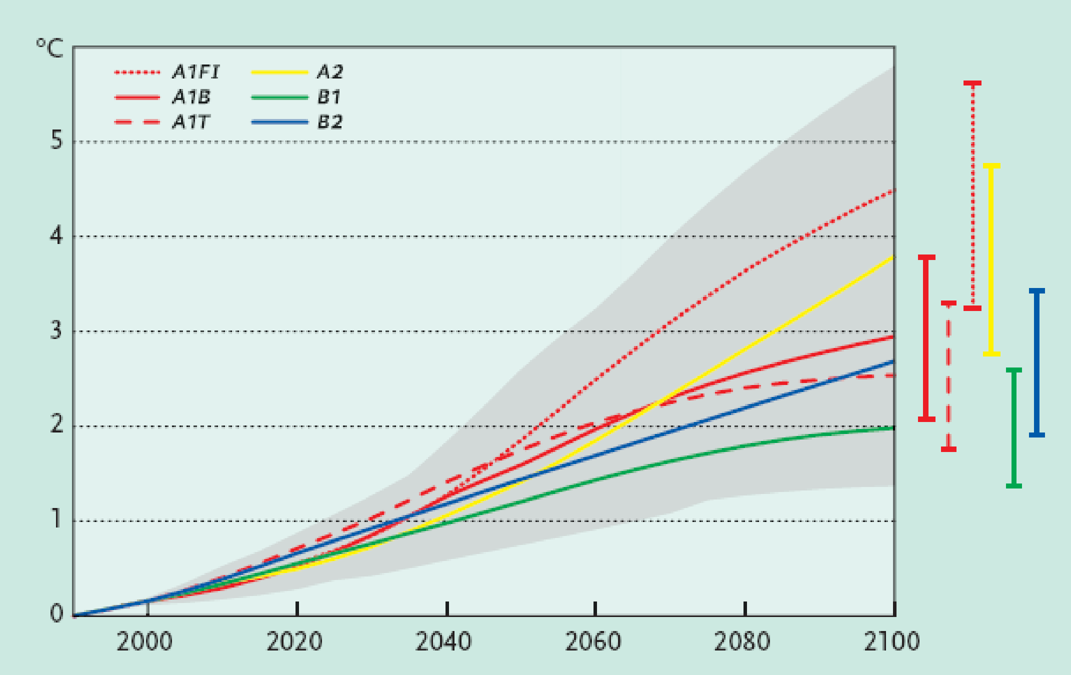

Figure 2: Global temperature projections for six land-use and climate change scenarios (from IPCC 2001). The grey area indicates the range produced across all six models, while the bars at the right hand of the graph show the range produced by the various scenarios in 2100. For further details on the various scenarios we refer to the IPCC website: http://www.ipcc.ch/.

The changes in temperature increase have two components: 1) increase in the mean temperature, and 2) increase in variance of the temperatures, leading to more extremes. These two components operate in concert and their combined effect leads to a disproportional increase of extreme warm days. Both effects and their combination are illustrated in Figure 3.

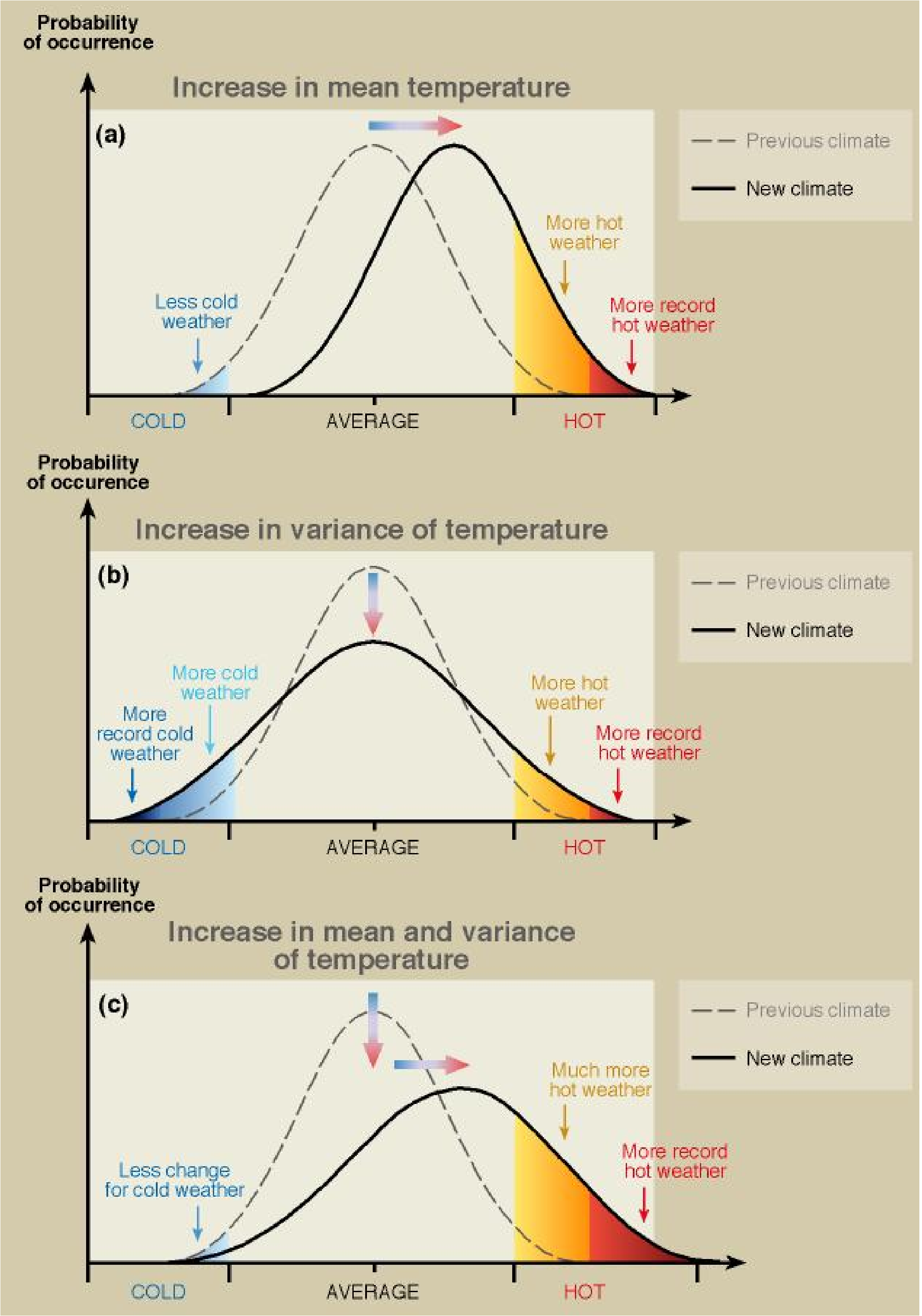

Figure 3: Illustration of the effect of two basic components of temperature changes on the occurrence of extreme cold and warm days. Pane a): symmetric increase in the mean temperature; b): increase in variance, and c) combined effect of increase in both mean and variance (from IPCC 2001). From a plants perspective a symmetric increase in mean temperature (pane a and c) would imply a disproportional increase of extreme warm days relative to the previous situation.

Climate change scenarios for the Netherlands

For the Netherlands climate change projections have been developed by the Royal Netherlands Meteorological Institute, KNMI, (2003), based on the results of the Intergovernmental Panel on Climate Change, IPCC, (2001) scenarios. An overview of the predicted climate changes in 2100 are given in Box 2.

Box 2: Summary of the predicted climate change in the Netherlands for 2100 (KNMI 2003). The values are based on the central estimates while the values between brackets are based on the low and high estimates.

Predicted climate for the Netherlands in 2100

Higher temperatures

Increase in mean temperature of 2°C (1-6°C)

Dryer summers

Slightly more summer precipitation (1-4%) and higher evapotranspiration (4-16%) with the net effect that there is a higher probability on summer droughts.

Wetter winters

Increase in winter precipitation with 12% (6-25%).

More extreme weather events

Higher frequencies of extreme droughts and of extreme heavy rains with the net effect that water levels will stronger fluctuate.

Increased sea level

The sea level is expected to increase with 20cm (20-110cm).

1.3 Plant responses to climate change

An increasing number of climate impact studies of a wide range of habitats, regions and species, provide compelling evidence that climate change is already affecting the behaviour and distribution of plant species and the composition and structure of communities and ecosystems (Hughes 2000, McCarty 2001, Walther et al., 2002, 2005, Stenseth et al., 2002, Parmesan & Yohe 2003, Root et al., 2003, Tamis et al., 2005). At the species level, climate change may influence the performance of plants in various, interrelated, ways (Dahl 1998, Hughes 2000, Walther et al., 2002).

Changes in physiological processes

Many physiological processes in plants have distinct optima with regard to temperature and air humidity. Climate changes will therefore directly influence plant performance. In addition climate change has many more indirect effects. An example of these indirect effects is the effect of climate on competitive interactions. Several alpine species are restricted to cold climates because they have low competitive abilities for light and nutrients in denser vegetation in warmer areas (Dahl 1998, Aerts et al., 2006). Climate change also affects the relative competitive ability of plants with different photosynthetic pathways. The so-called C4 and CAM photosynthetic mechanisms equip plants with a competitive advantage relative to C3 plants under conditions of high temperature, low water availability and high light availability. Periodic drought together with high daytime temperature may be environmental forces to hand the competitive advantage from C3 to C4 species (Moore 1994, Sage 2004). C4 grasses dominate nearly all grasslands in the tropics, subtropics and warm temperate zones, and especially occur in arid and saline landscapes (Sage 2004) but their frequency of occurrence has been shown to increase in several temperate areas (Cheffings et al., 2005, Tamis et al., 2005). Comparative data on direct and indirect effects of climate change on physiological processes are however not available for large sets of plant species.

Habitat suitability

Climate has a strong influence on the environmental characteristics of habitats. From a species perspective, climate change thus may lead to changes in the suitability of habitats and therewith in changes in the spatial configuration of habitats. For more details on the effects of climate change on the landscape level we refer to the WOT project on climate change effects at the landscape level (Corporaal et al., 2007).

Demographic processes

At the level of metapopulations climate change leads to changes in the dynamic balance between colonization and local extinction. Especially an increase in weather extremes may lead for some species to an increased rate of local extinctions and may therewith shift the dynamic balance between colonization and local extinction towards the extinction side. The indications for dispersal ability as developed in the present projects are therefore not only relevant in relation to habitat fragmentation but also in relation to climate change in itself (see also §1.4 for further details).

Changes in phenology

Climate change might also influence the timing of various periods in the life-cycle of plant species as has been demonstrated by Fitter & Fitter 2002 and Van Vliet et al., 2002; see Table 1). Some caution in the interpretation of results is needed however since planted individuals originating from southern areas (with a different genetic variation) may show pronounced differences in phenology relative to autochthonous populations. This has been shown for example for *Cornus mas*, *Crataegus* spec. and *Prunus* spec. (Londo 2006, Maes et al., 2006).

Genetic adaptation

There are a few examples of rapid genetic adaptations to changing environmental conditions (Jump & Peñuelas 2005). In general however plant species appear to be rather conservative with regard to habitat requirements due to phylogenetic constraints (Prinzing et al., 2004).

Range shifts

The net effects of the aforementioned processes ultimately culminate in changes in the geographical distribution of plant species. The geographical range of individual species is the result of a combination of climatic, environmental, biological and historical processes. Since climate change affects all other processes, it is in potential a strong driver of range shifts. At present there is already widespread evidence of pole-wards and uphill range shifts for many species, from many taxonomic groups (Walther et al., 2002, Parmesan & Yohe 2003, Root et al., 2003). Range characteristics might therefore be useful for the development of simple sensitivity scores for usage in nature policy. In this project the focus is therefore on range characteristics at the species level. This approach is based on the premise that range limits are partly determined by climatic conditions such as temperature of the warmest month, temperature of the coldest month and humidity (see Figure 4). More details are given in the methods section.

Table 1: Flowering phenology of a selection of vascular plant species in the Netherlands (after Van Vliet et al., 2002, 2005). Numbers represent the period of observed flowers: 1: very early; 2: early; 3: normal; 4: late; 5: very late.

	1-10 Dec	11-20 Dec	21-31 Dec	1-10 Jan	11-20 Jan	21-31 Jan	1-10 Feb	11-20 Feb	21-28 Feb	1-10 Mrt	11-20 Mrt	21-31 Mrt	1-10 Apr	11-20 Apr	21-30 Apr	1-10 May	11-20 May	21-31 May	1-10 Jun	11-20 Jun
Corylus avellana, past				1	2	2	3	3	3	4	4									
Corylus avellana, present			1	2	2	3	3	4	4	4	5									
Galanthus nivalis, past					1	1	2	2	2	2	4									
Galanthus nivalis, present		1	1	2	2	3	3	4	5											
Alnus glutinosa, past						1	2	2	3	3	4									
Alnus glutinosa, present					1	1	2	3	3	4	4									
Tussilago farfara, past							1	2	2	2	3	3	4	4	5					
Tussilago farfara, present							1	2	3	4	4	5								
Cornus mas, past							1	1	2	2	3									
Cornus mas, present					1	1	2	3	3	4	5									
Ranunculus ficaria, past								1	1	2	2	3	3	4	5					
Ranunculus ficaria, present						1	2	2	3	3	4	4	5							
Viola odorata, past								1	1	1	2	2	3	4	4	5				
Viola odorata, present						1	1	2	2	3	3	4	4	4						
Anemone nemorosa, past										1	2	2	3	4	4	5				
Anemone nemorosa, present								1	2	2	3	3	4	4	5					
Caltha palustris, past										1	1	2	3	3	4	5	5			
Caltha palustris, present								1	1	1	2	3	3	4	5	5				
Prunus spinosa, past											1	1	2	3	4	5				
Prunus spinosa, present							1	1	2	2	3	4	5							
Anthriscus sylvestris, past												1	1	2	2	3	4	5		
Anthriscus sylvestris, present								1	1	1	1	2	2	3	4	5				
Alliaria petiolata, past													1	2	3	3	4	5		
Alliaria petiolata, present													1	2	3	4	5			
Crataegus monogyna, past														1	2	2	3	4	5	
Crataegus monogyna, present													1	2	3	4	5			
Nuphar lutea, past																1	2	3	4	5
Nuphar lutea, present														1	1	2	2	3	4	5
Sambucus nigra, past																1	1	2	3	3
Sambucus nigra, present													1	1	2	2	3	3	4	5

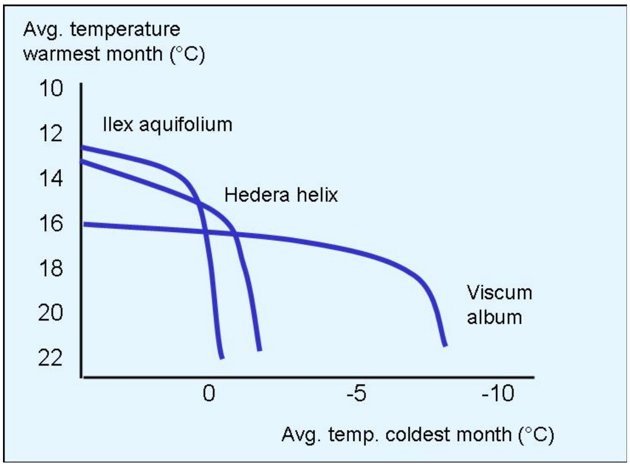

Figure 4: Temperature limit curves for three forest species. The curves give the range limit of the species relative to the average temperature of the coldest and the warmest months. The figure shows that Holly (Ilex aquifolium) is the most demanding species when it comes to winter temperature, while Mistletoe (Viscum album) can tolerate relatively low winter temperatures provided that the summer temperature is sufficiently high (after Moen 1999).

Model predictions on climate change effects on plants

Several studies used correlations between past and current distribution patterns and climatic variables to extrapolate future distributions under climate change (Bakkenes 2002, Thomas et al., 2004, Thuiller et al., 2005). Not all climatic variables are biologically meaningful. Climate envelopes for vascular plants should at least reflect summer and winter temperatures and a measure for available moisture (Dahl 1998, Bakkenes et al., 2002).

Thuiller et al. (2005) have presented model predictions on the potential effects of climate change on a sample of 1,350 plants, for the period 2051-2080. They used four of the scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC), namely scenarios A1, A2, B1, and B2.

The results of this study led to great variations in predictions of plant species losses across scenarios. However, the authors estimate that more than half of the European plant species could be vulnerable or threatened by 2080. The authors also suggest that plant species losses and turnovers correlate two climatic key factors: temperature and moisture conditions.

Within a single scenario, authors report great variations across regions. The obtained results suggest that plants in mountainous regions are the most vulnerable. In contrast, plants in the Mediterranean and the Pannonian regions seem to be the most resistant to the effects of climate change. The authors also identified a transition zone including the Boreal and Pannonian regions where great species mixing is expected to occur between 2051 and 2080.

Although such a correlative approach gives an indication of possible climate change effects on the distribution of plant species, it should be kept in mind that it does not yet provide insights in cause-effect relations.

1.4 Climate change and habitat fragmentation: Can plants track climate change?

An important question in predicting the effects of climate change on vascular plants is therefore: Can plant species track changes in spatial configuration of suitable habitats as a consequence of climate change? For some species the required migration rates due to climate change might exceed their dispersal ability. The inability of plant species to track climate change might be reinforced by habitat fragmentation. The degree to which species can track changes in the spatial occurrence of suitable habitats across Europe is critically dependent on their ability for long-distance seed dispersal (Ozinga et al., 2005a, 2005b).

Metapopulation theory predicts that for a given plant species, only a fraction of suitable habitat patches are actually occupied, because species continually become extinct on a local scale (<100m^2) and the dispersal ability of most (if not all) species is expected to be limited, at least at larger spatial scales (Levins 1969, Eriksson 1996, Hanski 1998, Ozinga et al., 2005b). Traits affecting species' dispersal ability and local persistence can be expected to influence the dynamic equilibrium between colonisation and local extinction (Tilman 1994, Ozinga et al., 2005b). This may translate at the community level into differences in local species composition between plots with the same environmental conditions. Local species composition is therefore the net result of niche based processes and dispersal processes (see Fig. 5).

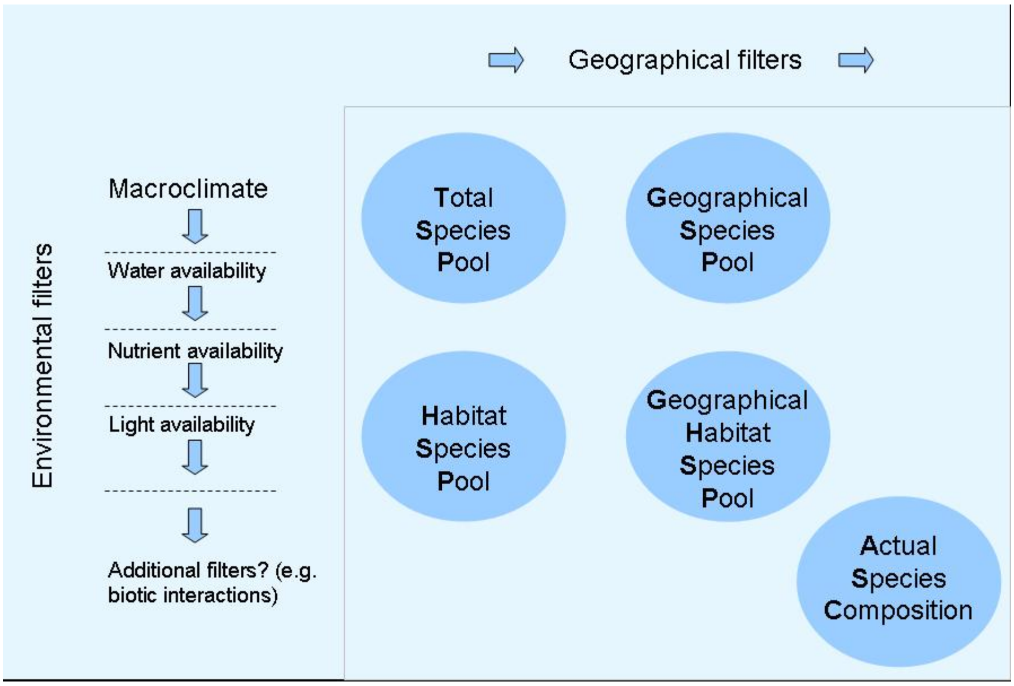

Figure 5: Conceptual model illustrating the combined effects of climate, environmental conditions and dispersal on local species composition (from Ozinga et al., 2005a). During the assembly of local plant communities from the total pool of available species the various processes operate like filters. The response of plant species to changes in local habitat conditions (i.e. availability of water, nutrients and light) is relatively well known. In the present project the focus is on climate and dispersal which both operate at larger spatial and temporal scales.

Until now, models on the effects of climate change on vascular plants have hardly taken differences between species in their dispersal ability into account. This is also true for EUROMOVE and the modelling results are based on the assumption that plant species can reach suitable sites. This may lead to an underestimation of the effects of climate change on changes in distribution patterns.

Bakkenes et al. (2002) and Thuiller et al. (2005) used two hypotheses concerning the potential migration rate of plant species across Europe: no migration and universal migration. The 'no migration' hypothesis was used to estimate the potential number of species losses after the disappearance of their climatic niche. In contrast, the 'universal migration' hypothesis was used to estimate the potential gains and turnovers of plant species following climate changes.

The inclusion of dispersal in climate response models is not straightforward since dispersal models are in its infancy. Most progress has been achieved for models on wind dispersal (Soons et al., 2004, Soons & Ozinga 2005; Katul et al., 2005), but even here generalisations across entire landscapes are hardly possible (Clark et al., 2003; Nathan et al., 2005). For seed dispersal by other vectors (e.g. water, mammals, birds) the situation is even worse. Within the present project we will take therefore a more practical approach by quantifying sensitivity scores for climate change and habitat fragmentation for vascular plant species from the Netherlands. A conceptual model of the possible combined effects of climate change and habitat fragmentation on range characteristics is given in Figure 6.

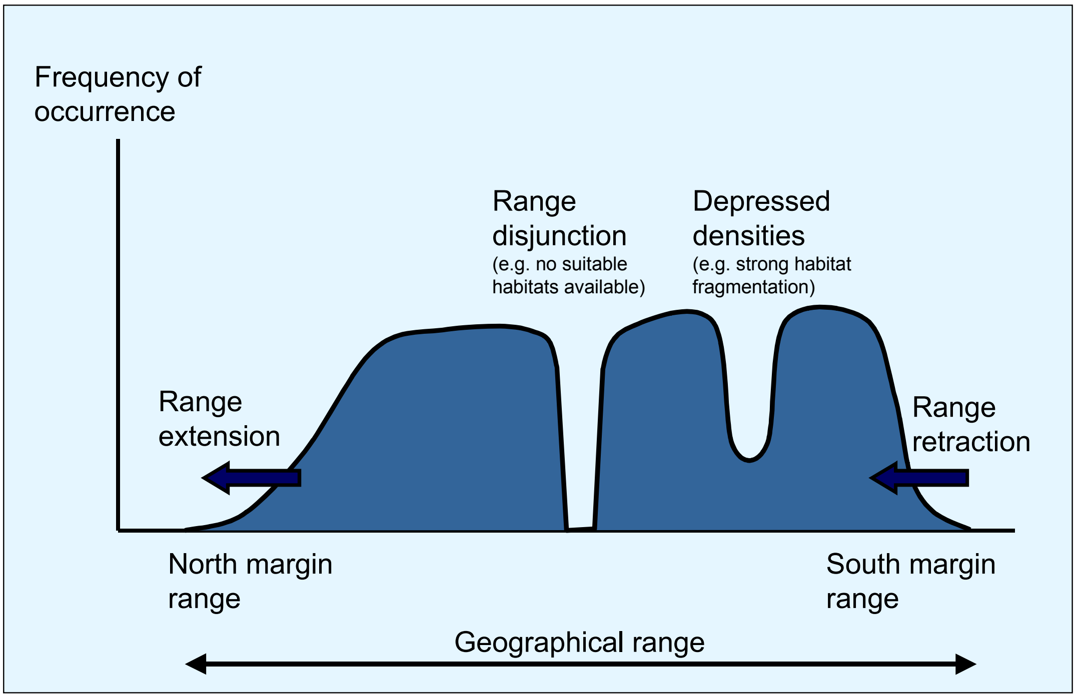

Figure 6: Schematic cross-section of the geographical range of a species along a north-south transect. The crosscut passes through a range-disjunction in which no suitable habitats are available and through an area with a depressed frequency of occurrence due to habitat fragmentation. In the latter area, increased weather variability may cause a relatively strong drop in the degree to which suitable habitat patches are occupied. This low frequency of occurrence in turn strongly increases the risk of regional extinction, leading to a new range-disjunction (modified after Opdam & Wascher 2004).

2 Methods

2.1 Approach

The European Union has the ambition to halt the loss of biodiversity by 2010 (EU headline biodiversity indicators). In order to achieve this goal, the EU is interested in tools to assess the response of plant and animal species to various environmental pressures and to assess the potential effects of various policy scenarios.

In the present project we developed a simple system with species specific sensitivity scores for climate change and habitat fragmentation. The sensitivity scores will be made available within the BioScore project. It should be kept in mind that these sensitivity scores are only meant as a first approximation that needs further improvements, since the response of plant to both climate change and habitat fragmentation is rather complicated.

2.2 Sensitivity scores for climate change

For the possible response to climate change we used two approaches: an existing regression model for 20% of the European vascular plant species (EuroMove) was complemented with an approach based on the characteristics of geographical ranges of plant species (size and position of the Netherlands within the range).

2.2.1 EuroMove

Model description

EUROMOVE is a climate response model developed at the Netherlands Environmental Assessment Agency by Bakkenes et al. (2002). The model description below is mainly based on Bakkenes et al. (2002, 2006). EUROMOVE is a niche-based species distribution model that relates observations of almost 1,400 European vascular plant species to various climate characteristics. Using multiple logistic regression equations, the occurrence probabilities across Europe are calculated for this subset of European vascular plant species and subsequently the model projects fitted ‘climatic envelopes’ to future climate scenarios.

Distribution data for plant species are derived from Atlas Florae Europaeae (Jalas & Suominen 1972-1999, Ascroft 1994, Kurtto et al. 2004). Atlas Florae Europaeae (AFE) includes about 20% of the European vascular flora. The species are covered according to their taxonomy, i.e. Pteridophytes to Rosaceae in the Flora Europeae system (Tutin et al., 1993). From the 1763 Dutch species considered in the present study, 16 % are included in EuroMove.

Climate variables in EUROMOVE were derived from the IMAGE2 model which is based on measurements at an array of weather stations (Alcomo 1998). The measured and interpolated climate variables were projected onto the AFE grid. In order to prevent over-fitting, the EUROMOVE model is based on a selection of six climatic variables from IMAGE2 based on the results of principal component analyses (see Table 2).

The selected climate variables for 1990 were related to the distribution data (presence-absence) using multiple logistic regression. Since the results of regression models are in terms of probabilities it was needed to define species specific threshold values above which the species was assumed to be present (cf. Huntley et al., 1995). For each species the threshold was set at a value that maximises the match between observed and predicted occurrences (Bakkenes et al., 2002, 2006). For each grid cell the model predicts whether species disappear, newly appear or remain present (stable).

Table 2: Climate variables from the IMAGE2 model that were considered for EuroMove. Several variables are highly correlated and in order to prevent over-fitting a selection of these variables was made for usage in EuroMove (after Bakkenes et al., 2002).

Climate variable	Unit	Used in EuroMove
Temperature of the coldest moth	°C	X
Effective temperature sum above 0°C	degree-days	-
Effective temperature sum above 5°C	degree-days	X
Temperature of the warmest moth	°C	-
Alpha moisture index	-	X
Annual precipitation	Mm	X
Annual potential evapotranspiration	Mm	-
Annual actual evapotranspiration	Mm	-
Length of growing season	# days	X
Start of growing season	Day	-
Mean growing season temp. above 0°C	°C	-
Mean growing season temp. above 5°C	°C	X
Annual runoff	Mm	-

Various IMAGE climate change scenarios are available as input for EuroMove. These scenarios have different assumptions about trends in the main driving forces (population and economic growth), trends in environmental pressures (emissions from energy, industrial and land use) and their resulting effects, such as temperature increase (IPCC 2001, Van Vuuren et al., 2003). Within the present project we used a baseline scenario (Van Vuuren et al., 2003) (see Bakkenes et al., 2006). The population scenario assumes a global population stabilisation at 9.5 billion by 2100. On the economic side, the baseline scenario describes a world in which globalisation and technological development continue to be important factors underlying economic growth, although not as important as assumed in the IPCC A1b scenario (Nakícenovíc et al., 2000).

To assess the consequences for ecosystems, the global mean temperature change needs to be downscaled to local levels where the behaviour of plants can be modelled. General circulation models (GCMs) are currently the best tools available for simulating the physical processes that determine global climate dynamics and regional climate patterns. We used different climate change patterns from four GCM simulations and analysed the results with the EUROMOVE model (Bakkenes et al., 2006). The climate pattern of the general circulation model 'HADCM-2' was used within the present project. Detailed information on the GCM simulations can be found on the web site of the IPCC Data Distribution Centre (www/ipcc-ddc.cru.uea.ac.uk/).

Model performance

The model performance was quantified by comparing the occurrence data from Atlas Flora Europaeae with the predicted occurrences in 1990 on basis of the regression model. The comparisons were based on the Kappa coefficient which gives a standardized classification of the proportion of agreement between two maps and which is corrected for the percentage of agreement when random allocating the observations. Kappa values were interpreted using the ranges of agreement from Landis & Koch (1977): 0.85; very good K > 0.70; good K > 0.55; fair: K > 0.40; poor K > 0.20; very poor K < 0.20. Although there was considerable variation between species in the model performance, the mean Kappa value for all species was 0.45

which is considered as ‘fair’. Within the total species set, 61% of the species had a match of ‘fair’ to ‘good’.

2.2.2 Range characteristics

Since EuroMove contains information for only 20% of the European plant species, it is worthwhile to consider additional information that might be of importance for the response of plant species to climate change. Both size and the position of geographical ranges are expected to be strongly related to the sensitivity for climate change. Regional extinction risk is expected to be the highest for species with small ranges and for species where the area of interest (i.e. the Netherlands) is at the southern border of their distribution area.

Digital information on the geographical distribution of vascular plants that are not included in Atlas Flora Europaea is not available in a standardized way and is often incomplete and scattered throughout the literature. For the present project range characteristics were derived from many sources, the most important ones include: Dahl 1998, Hultén et al., 1958-1986, Jalas et al., 1972-1991, Maes et al., 2006, Meusel et al., 1965-1992, Ozinga & Schaminée 2005, Schaminée et al., 1992, Tutin et al., 1964-1980, Van der Meijden 2005 and the expert system SynBioSys Europe (Schaminée & Hennekens 2005, Schaminée et al., 2007).

Naturalness of Dutch populations

Within regional floras the highest conservation concern is in general assigned to native species for which the area under consideration forms part of its natural range (IUCN 2004, Cheffings & Farrell 2005). We therefore distinguished between native species and non-native ‘alien’ species. The latter group was subdivided according to the period of introduction (Table 3). Species that were introduced by humans before AD 1500 are called ‘archaeophytes’ and species introduced after 1500 are called ‘neophytes’. Neophytes have their main range outside the Netherlands and from an international perspective the responsibility of the Netherlands for these species is limited. In addition to this ‘wild’ plant species, we screened the recent floristic literature for species that are in the process of becoming able to maintain itself in the wild (so called ‘waiting-room species’). Furthermore, we included information on the area of origin, since the original range may provide some information on their climate requirements. Data were derived from Tamis et al., (2004), van der Meijden (2005) and many floristic books and journals.

Table 3: Classification of the naturalness of the Dutch part of the geographical range.

Class	Description
I	Indigenous: native in the Netherlands
A	Archaeophyt: introduced by humans before AD 1500
N	Neophyt: introduced by humans after AD 1500
W	Waiting-room species: species in the process of becoming naturalized
?	Uncertain

Range size

Information on the range size and more specific on the proportion of the Dutch part of the range population within the total geographical range was obtained from Ozinga & Schaminée (2007). Species with a small geographical range are expected to be more vulnerable for climate change. The classification of the proportion of the Dutch part of the range within the total geographical range is given in Table 4.

Table 4: *Classification of the proportion of the Netherlands within the European range.*

Class	Description
A	>50% of the European range within the Netherlands
B	>10% of the European range within the Netherlands
C	>1% of the European range within the Netherlands
1	<1% of the European range within the Netherlands
?	Uncertain

Range position

The position of a given population within its entire range is expected to be an important factor for the vulnerability of this population to climate change. This is based on the assumption that marginal populations experience climate conditions that are farther removed from the optimal climate as compared to populations near the centre of their range (Brown et al., 1995). For each species the position of the Netherlands relative to its main range is quantified (Table 5). In addition, the position of the Netherlands relative to its main range in Europe is quantified on a north-south (Table 6) and an east-west axis (Table 7). North-south patterns in geographical ranges in Northwest Europe are often strongly correlated to the amount of heat in the growing season and, related to this, to the mean temperature of the warmest month (see Fig. 7A). East-west patterns in Northwest Europe are often strongly correlated to mean temperature of the coldest month and to evapotranspiration in the growing season (see Fig. 7B). In Atlantic regions in Western Europe, winters are mild, summers cool, atmospheric humidity is high and precipitation is fairly evenly distributed through the year. It should be noted however that on a European scale relationships between climate and geographical ranges are far more complicated.

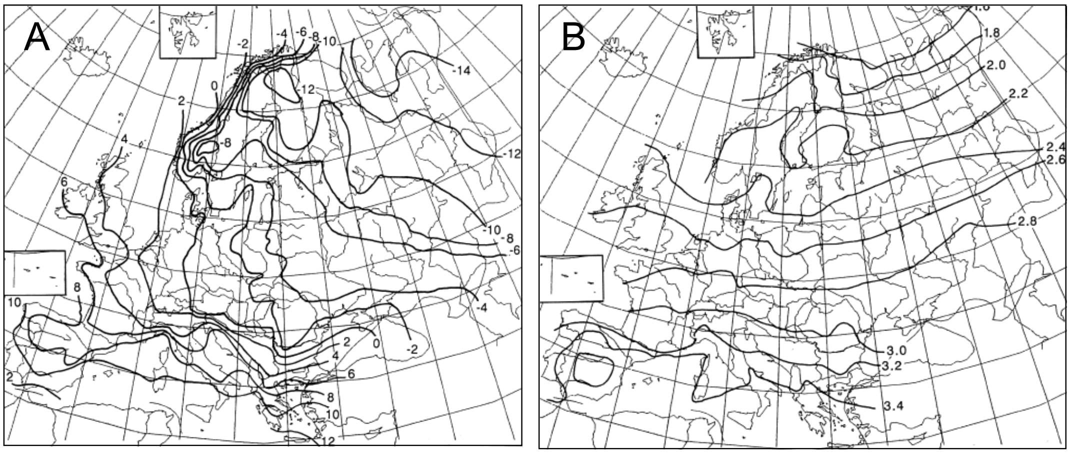

Figure 7: Two climate maps for Europe from Dahl 1998). Pane A depicts isolines of the mean monthly temperature of the coldest month (°C) calculated for sea level. Pane B gives isolines for the respiration equivalent as a measure for the amount of heat received in the summer. This respiration value is based on the accumulated sum of temperatures throughout the growing season weighted according to the effect of temperature on dark respiration of plants.

Table 5: Classification of the position of the Netherlands for a given species relative to the main range (after Schaminée et al., 1992).

Class	Description
C	Central
S	Sub-central
M	Marginal
V	Outpost
B	Outside natural range (non European neophytes)
?	Uncertain

Table 6: Classification of the position of the Netherlands for a given species relative to the main range along a north-south axis.

Class	Description
N	Northern species for which the Netherlands are near the southern border of the geographical range
I	Indifferent
S	Southern species for which the Netherlands are near the northern border of the geographical range

Table 7: Classification of the position of the Netherlands for a given species relative to the main range along an east-west axis.

Class	Description
E	Eastern species for which the Netherlands are near the western border of the geographical range
I	Indifferent
W	Western (Atlantic) species for which the Netherlands are near the eastern border of the geographical range

2.3 Sensitivity scores for habitat fragmentation

Dispersal ability

Three life history traits are considered to be important for the spatial and temporal dynamics of plant species (cf. Tilman 1994, Eriksson 1996, Ozinga et al., 2005b), namely: (1) potential for long-distance dispersal, (2) adult persistence, and (3) potential to build up a persistent soil seed bank ('dispersal in time'). These three traits are expected to contribute positively to dispersal, that is a high value for these traits reduces the degree of dispersal limitation and hence the sensitivity to habitat fragmentation. From these three traits, dispersal ability appears to be the most important one for the assembly of plant communities (Ozinga et al., 2005b) and therefore we only consider this trait.

The efficiency of seed transport of a given species can be classified based either on differences in actually achieved dispersal distance or on differences in attributes that potentially give access to dispersal vectors. Long-distance dispersal (LDD: >100m; Cain et al., 2000) depends on the 'tail of the dispersal kernel' and is extremely difficult to quantify (Cain et al., 2000, Nathan & Muller-Landau 2000, Nathan et al., 2002). The probability of ending up in the tail of the dispersal kernel is not only dependent on traits of the species, but is also strongly dependent on weather conditions and landscape characteristics such as vegetation structure, the presence of barriers and availability of dispersal vectors. Due to the strongly case specific nature of dispersal, it is not realistic to quantify precisely the probability of seeds dispersing over distances of >100m for many species under various conditions for all dispersal vectors. Since differences in attributes that determine the degree of access to various dispersal vectors can be quantified more easily, we have adopted a trait-based approach. Data on dispersal ability by various vectors were extracted from the LEDA database (Knevel et al., 2005, Kleyer et al., in prep., www.leda-traitbase.org) and adapted to our classification (Ozinga et al., 2004, 2005b). We considered the following dispersal vectors, all providing efficient long-distance dispersal: water, wind, the fur of large mammals, the digestive tract of large mammals and the digestive tract of frugivorous birds. We aggregated the available data into a simple classification (3 ordinal classes) in order to include as many species as possible and to enhance comparisons between traits (see Table 8).

Table 8: Classification of dispersal ability. Dispersal distance is very context dependent and the given distances are only intended to give an indication of the order of magnitude of the potential dispersal distance.

Class	**Dispersal ability**
1	Low dispersal ability; no attributes that facilitate dispersal over distances >100m
2	Intermediate dispersal ability, attributes that facilitate dispersal over distances >100m and less than <1000m
3	High dispersal ability, attributes that facilitate dispersal over distances >1000m

2.4 Trend data

Since the proof of the pudding is in the eating, we linked the sensitivity scores for individual plant species for climate change and for habitat fragmentation to recent trend data. The conference of Parties for the Convention on Biological Diversity agreed upon a set of indicators to be tested for describing status and trends of components of biological diversity. Based on this set the EU selected the following headline biodiversity indicators (Malahide declaration):

1. Trends in extent of selected biomes, ecosystems and habitats;
2. Trends in abundance and distribution of selected species;
3. Change in status of threatened and/or protected species;
4. Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance;
5. Coverage of protected areas.

This project focuses on the second headline indicator (Trends in abundance and distribution of selected species). Trends in the frequency of occurrence were assessed using published national surveys of the occurrence of vascular plant species in grid cells (quadrats). Since trend data are sensitive to various sources of bias and to differences in spatial and temporal scale (Telfer et al., 2002, Tamis 2005), we aggregated species trend into three classes: declining, stable, and increasing.

Within this project we only considered trends in the Netherlands, since trends in other countries are not comparable due to large differences in methods and scale of observation. The trends for the Netherlands are based on changes in frequency of occurrence within 1*1 km grid cells between 1975-1987 and 1988-1999 as available in the FLORON database. Data were derived from Tamis et al., (2004). Many very recently established neophytes were not included in these trend-lists. For these species we screened the recent floristic literature. We also searched for comparable sets of trend data for neighbouring countries, but the available data are too different with regard to scale and methods that a comparison with other countries is not feasible at this stage.

3 Results and discussion

3.1 Sensitivity of vascular plants for climate change

Naturalness of Dutch populations

From a policy perspective it is useful to distinguish between species that are indigenous to the Netherlands (native species) and 'alien species'. The highest conservation concern is in general assigned to native species (IUCN 2004). The sensitivity of these species to climate change is dependent on their range characteristics (size and position). In the Netherlands 2/3rd of the plant species is considered as native (Figure 8).

For 'alien species' it is possible to make a further distinction according to their period of introduction into species introduced before AD 1500 (archaeophytes) and species introduced after 1500 (neophytes). Within the group of neophytes, most species were introduced in the 19th and 20th century. In addition there is a group of species (ca. 9%) that is in the process of becoming neophyte, i.e. able to maintain itself in the wild (Figure 8).

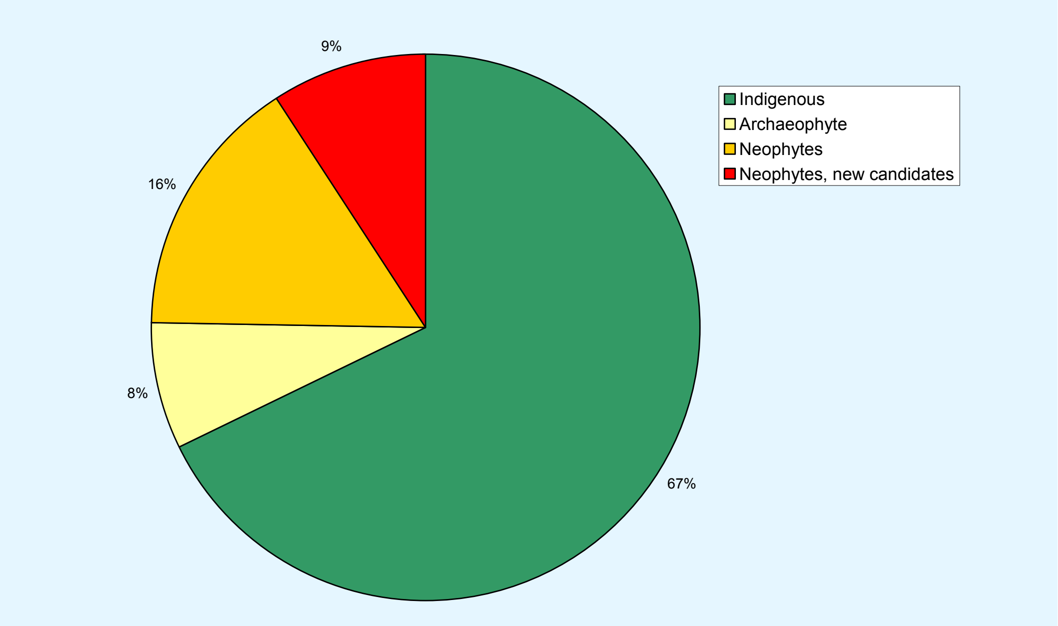

Figure 8: Status of plant species with regard to the naturalness of their range in the Netherlands and their period of introduction (N=1763). Indigenous species (native) have reached the Netherlands probably by natural dispersal processes. Archaeophytes were introduced by man before 1500, while neophytes were introduced after 1500. In addition there is a group of species (ca. 9%) that is in the process of becoming neophyte, i.e. able to maintain itself in the wild.

Range position

Within the group of native species (2/3rd of the total species pool, see Figure 8), the highest sensitivity to climate change is expected for species near their range limit. For the Netherlands this may be the case for a quarter of the species ('marginal' and 'outpost' in Figure 9).

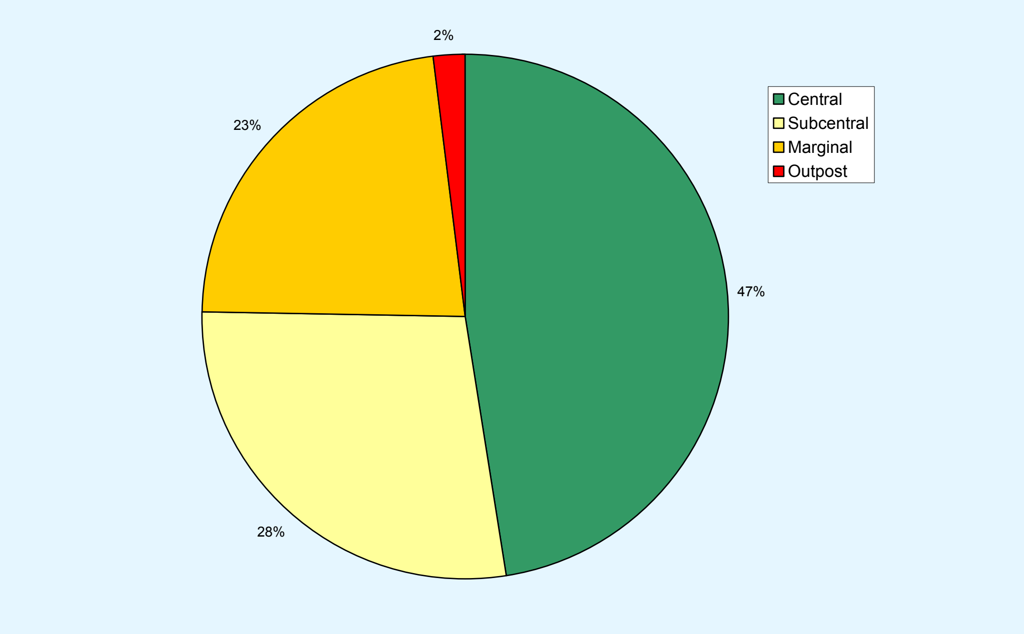

Figure 9: Position of the Netherlands relative to the centre and margin of the geographical range. Only native species are included (N=1124).

For the native species for which the Netherlands are not central in the geographical range it is useful to take a closer look at the position of the main range relative to the position of the Netherlands. This is illustrated in Figure 10 with a compass-card. Northern species are expected to run a relatively high risk of regional extinction due to temperature increases as compared to other species. The number of northern species in the Netherlands is however small (circa 14%; see Figure 10).

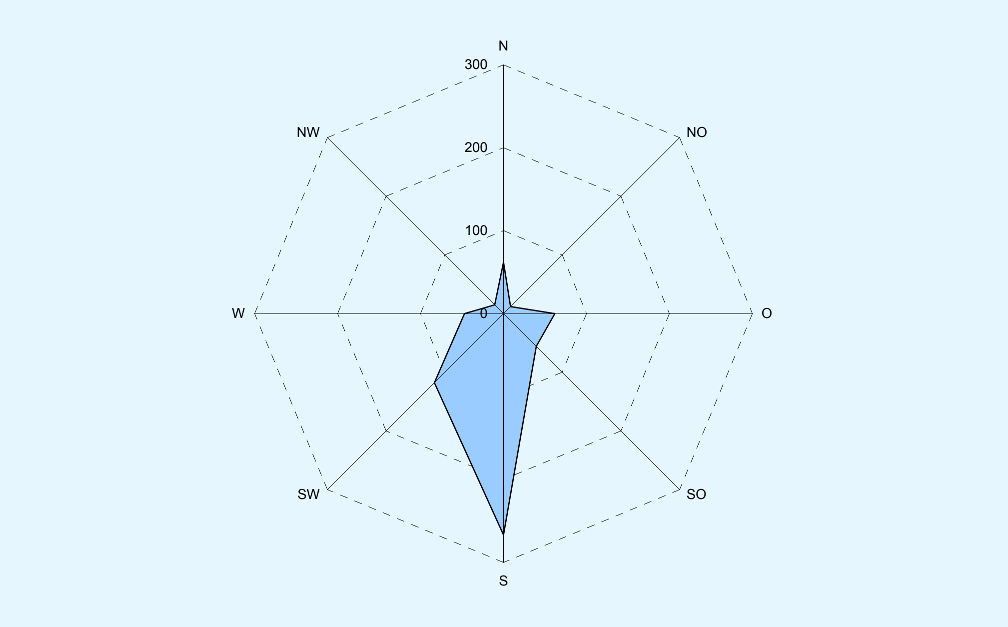

Figure 10: Position of the main range of native plant species relative to the Netherlands. Only species are included for which the Netherlands lay not in the central part of the geographical range.

Within the group of species that were introduced before AD 1500 (archaeophytes) there are no northern species at all. Although many archaeophytes probably stem from southern Europe or the Middle-East the natural range is often difficult to reconstruct. Indeed, some species are regarded as alien throughout their known global range.

For the species that were introduced after 1500 (neophytes) the area of origin is better documented. From Figure 11 it becomes apparent that over time the relative importance of central Europe as a source area for neophytes decreases while the importance of other continents increases.

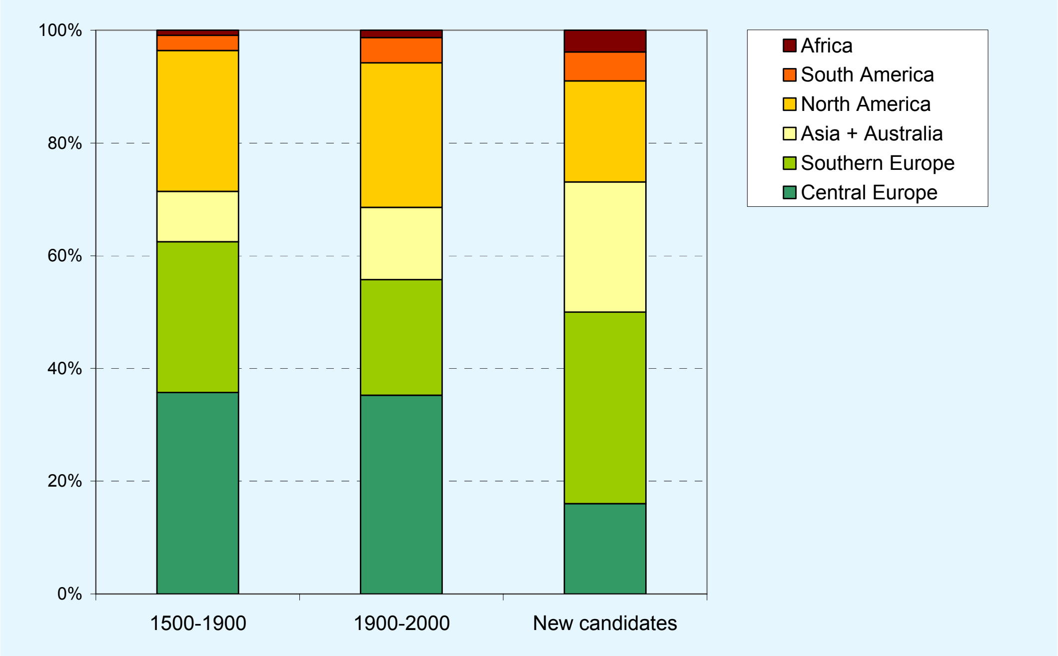

Figure 11: Area of origin of species that were introduced in the Netherlands by humans after 1500 (neophytes).

Comparison of EuroMove results with range characteristics

In the present project we used two approaches to quantify the sensitivity of plant species for climate change: modelling results from EuroMove and range characteristics. Range characteristics have the advantage that they are available for the majority of plant species, while modelling results are available for only 20% of the species. EuroMove however has the advantage that it provides more quantitative information in comparison because the sensitivity scores are not linked to spatial explicit probabilities of occurrence. If the concordance between both approaches is reasonable range characteristics may be used as a complement to the modelling results.

In Figure 12 a comparison is given between the modelling results of a climate change scenario from EuroMove and the sensitivity scores based on range characteristics. The choice of the climate change scenario is arbitrary and the comparison is only meant as an approximation. Despite the methodological difficulties in comparing both approaches the results are reasonably consistent. Differences in the scores can largely be explained by considering more detailed information. Among the 24 species that are predicted to disappear by EuroMove, for example, there are 3 species that are labelled as 'low risk' according to their range characteristics (*Parietaria officinalis*, *Silene noctiflora*, *Isatis tinctoria*). These species are all three introduced in the Netherlands by humans and their range in Europe is strongly influenced by human interference. This makes the predictability of occurrences based on climate variables lower. In fact two of these three species have shown a recent increase in the Netherlands (*Parietaria officinalis and Isatis tinctoria*).

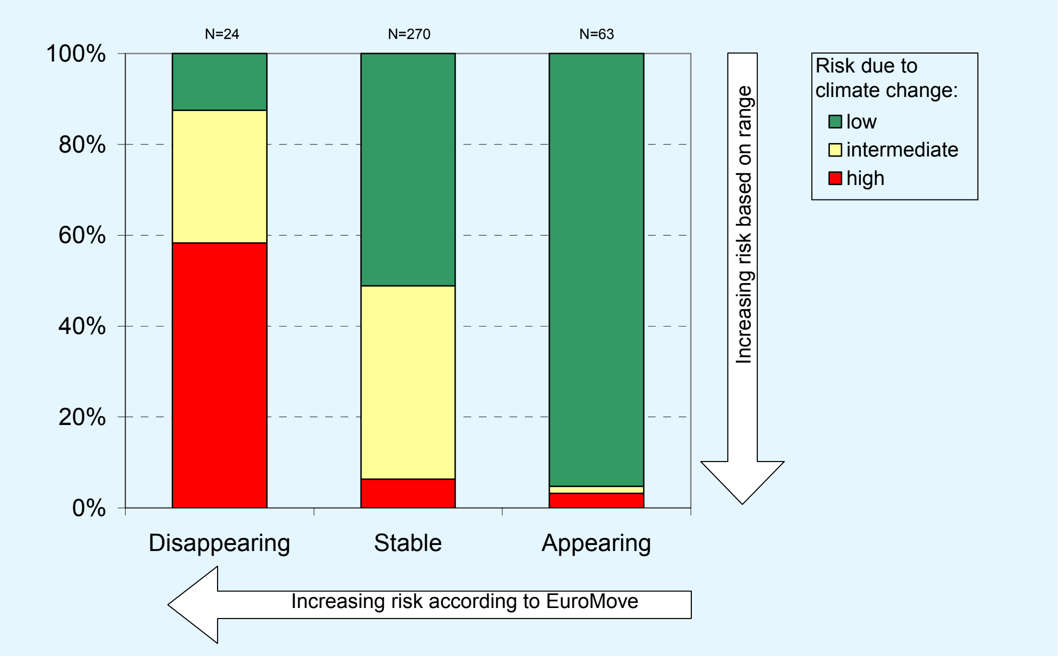

Figure 12: Comparison between the modelling results of a climate change scenario from EuroMove and the sensitivity scores based on range characteristics. EuroMove predicts for each species whether it will disappear, newly appear or remain present (stable). For the same subset of species the risk assessment according to range characteristics within the present project is given.

3.2 Dispersal ability of species that are sensitive to climate change

Although past climate change may not have caused many extinctions in Northwest Europe yet (Huntley & Webb 1989), future climate changes are likely to have considerable effects due to interactions with habitat fragmentation. Habitat fragmentation and changing land-use will strongly reduce the rate of seed dispersal and therewith affect the local balance between colonisation and extinction.

In Figure 13 the sensitivity scores for climate change and habitat fragmentation are combined. Dispersal ability in itself seems not related to range characteristics and the proportion of species with low to intermediate dispersal abilities is circa 70%.

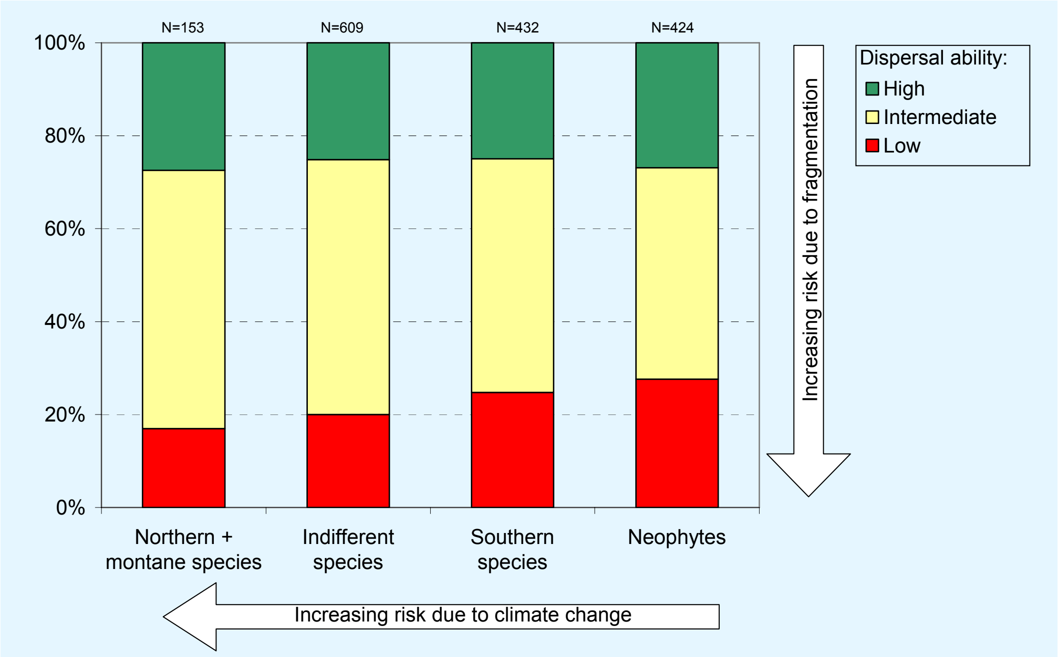

Figure 13: Overview of species numbers for different sensitivity classes. Species were classified according to the risk of negative effects due to climate change and due to habitat fragmentation.

3.3 Sensitivity scores in relation to observed trends

Northern species in decline

Climate change and habitat fragmentation may already explain part of the recently observed trends. In this section we confront sensitivity scores with trends based on changes in frequency of occurrence between 1975-1987 and 1988-1999. From Figure 14 it becomes apparent that among the native species a relatively high proportion of the species is in decline. Within the native species, the proportion of decreasing species is much higher for northern and montane species as compared to southern species. This is consistent with the patterns that would be expected in response to rising temperatures.

The other side of the coin: new species and invasive species

A different pattern emerges for the species that were introduced after 1500 (neophytes). Among these species the vast majority shows an increase in the frequency of occurrence. Climate change is probably one of the major contributing factors for the increasing tendency of exotic species dispersal and their capability to establish in various ecosystems in the Netherlands. This may lead to a reorganisation of a plant community with shifting ranges of indigenous species and pre-adapted non-indigenous species invading possible vacant niches (Walther 2000, Schmitz 2006).

At present, the number of invasive plant species in the Netherlands is limited. Examples include: *Amelanchier lamarckii*, *Aronia x prunifolia*, *Crassula helmsii*, *Fallopia japonica*, *Heracleum mantegazzianum*, *Hydrocotyle ranunculoides*, *Impatiens glandulifera*, *Ludwigia grandiflora*, *Prunus serotina*, *Robinia pseudoacacia*, *Rubus armeniaca*, *Solidago canadensis*, *S. gigantea*, *Vaccinium corymbosa*.

Many alien plants species are already causing, or have the potential to cause economic or environmental problems in Europe. Invasive alien species have been singled out worldwide as a high-risk group under the Convention on Biological Diversity. The degree of invasiveness is dependent on both plant traits and ecosystem properties. Plant species have a higher tendency to become invasive when there are locally high proportions of unused resources (Davis 2003). Climate change may lead to the development of new niches that are not yet filled with native species. Invasive species with good dispersal abilities may strongly profit from the development of these 'empty niches'. As a result climate change may lead to an increase in the proportion of invasive species on both the local and regional scale. In theory the decrease of a relatively high proportion of native species and the parallel increase of non-native or even non-European species (Figure 14) may in the long term lead to a kind of 'homogenization of biodiversity' in the Netherlands (cf. Davis 2003).

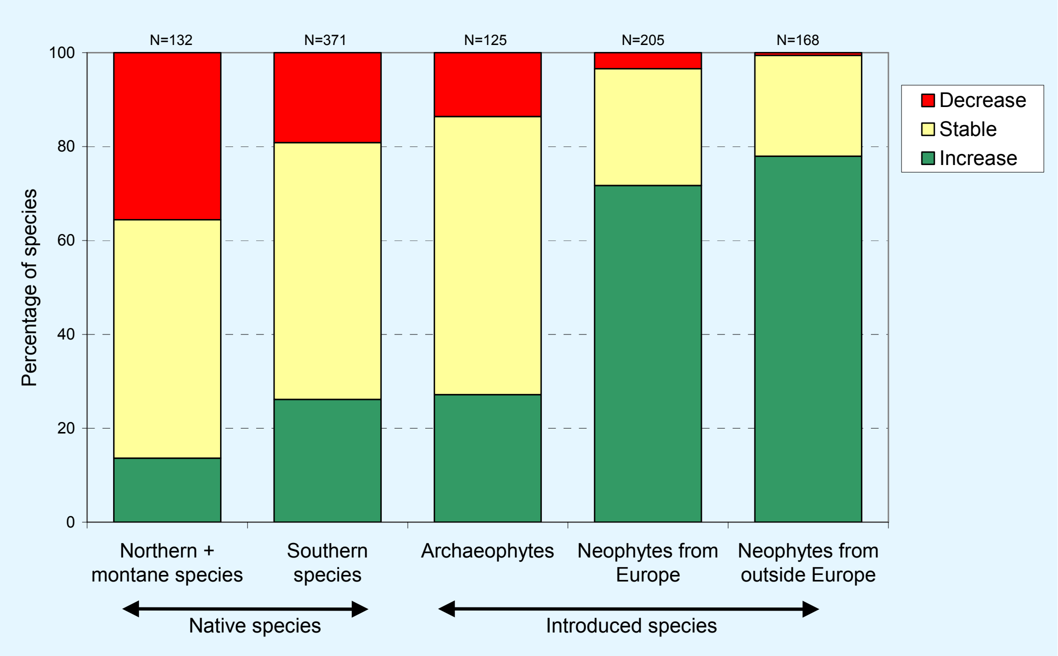

Figure 14: Range characteristics in relation to observed trends. The trends are based on changes in frequency of occurrence between 1975-1987 and 1988-1999. The left two columns contain native species for which the Netherlands are near the range margin, while the right three columns contain introduced species.

Urbanisation as an alternative explanation for observed trends

Urbanisation might provide an alternative explanation for observed trends. Urban habitats are characterised by higher temperatures and higher water losses to evapotranspiration. These circumstances show similarities to certain habitat types in Mediterranean and steppic areas (cf. Weeda et al., 2003). In addition human activities in large cities facilitate human assisted long-distance dispersal. The unravelling of the effects of climate change and urbanisation requires a more detailed, spatial explicit and habitat-specific analysis (see § 3.4).

Interaction effect between sensitivity for climate change and fragmentation

The relation between the sensitivity score for habitat fragmentation and observed trend differs between species with a high and a low sensitivity for climate change. Within the species with a low extinction risk due to climate change there are no detectable differences in trends between species with low respectively high dispersal abilities (Figure 15). A different pattern emerges within the group of species that are sensitive to climate change the highest proportion of decreasing species is observed among the species with low dispersal ability.

Ultimately, the different response of individual plant species may lead to the development of newly emerging communities with no modern analogue. In fact such community types with no modern analogue are common in the fossil record (Huntley 1991). Demonstration of this effect, again, requires a more detailed, spatial explicit and habitat-specific analysis.

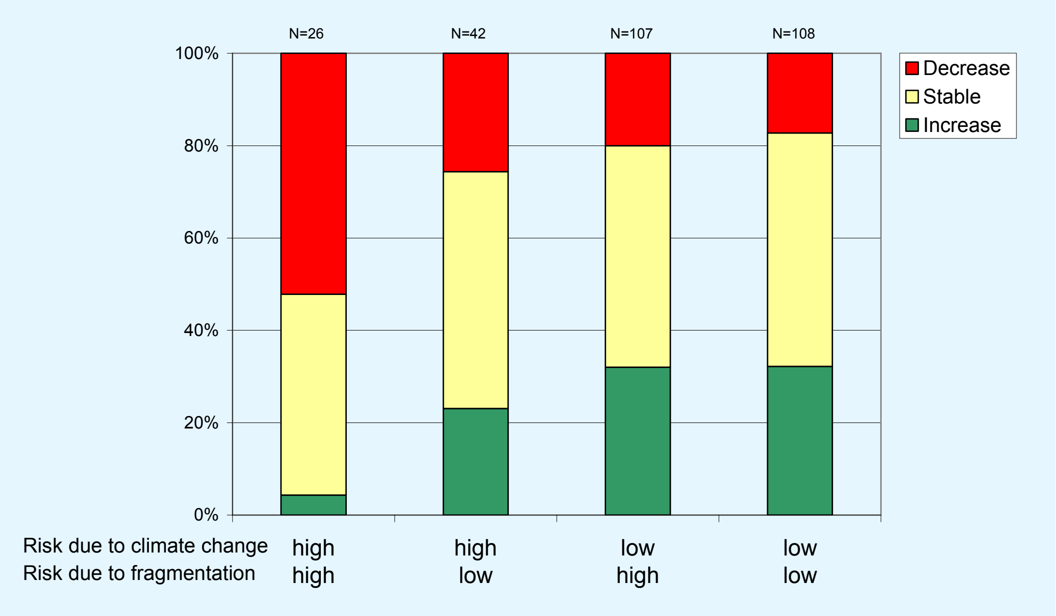

Figure 15: Sensitivity scores of native plant species for climate change and habitat fragmentation in relation to observed trend. The trend is based on changes in frequency of occurrence between1975-1987 and 1988-1999. Species with intermediate sensitivity scores are not shown.

4 Conclusions and recommendations

4.1 Conclusions

A first scan of the sensitivity of Dutch vascular plants to climate change and habitat fragmentation, based on plant traits in relation to past trends and future projections, has resulted in the following conclusions:

- It seems feasible to assign sensitivity scores for climate change and habitat fragmentation to vascular plant species for risk assessment studies. The mechanistic understanding of the effects of both climate change and habitat fragmentation of the local species composition, however, is poor and it should be stressed that the sensitivity scores as developed within the present study are meant to explore risks rather than to give precise predictions;
- There is a good correspondence between the results based on EuroMove and the results based on range characteristics;
- Both sensitivity scores for climate change and for habitat fragmentation can already explain part of the observed trends;
- Within the group of species that are sensitive to climate change the highest proportion of decreasing species is observed among the species with low dispersal ability;
- Native species show on average strongest decline;
- The number of southern species that might profit from climate change is relatively large in comparison to the number of northern and submontane species that are at risk. Species numbers on its own are therefore not a good indicator of climate change effects on vascular plants;
- The correlative approach taken in this study does not yet provide insights in cause-effect relations. Urbanisation for example might provide an alternative explanation for at least part of the observed trends. The unravelling of the effects of climate change, habitat fragmentation and urbanisation requires a more detailed, spatial explicit and habitat-specific analysis.

4.2 Research agenda

The mechanistic understanding of the effects of both climate change and habitat fragmentation of the local species composition is still poor and it should be stressed that the sensitivity scores as developed within the present study are meant to explore risks rather than to give precise predictions.

Based on the present approach there are two main lines of further development: in the first place the approach may be up-scaled towards Europe and in the second place the approach might be used in a more detailed habitat-specific analysis.

Spatial and habitat specific analysis

The possible role of climate change, urbanisation and dispersal in explaining changes in the occurrence of plant species is context dependent (differences between habitats and landscapes). Many effects of climate change on the performance of plant species are probably indirect through effects of physiological changes on the relative competitive ability of species. Comparative data on direct and indirect effects of climate change on physiological processes are however not available for large sets of plant species. The disentangling of these processes requires a more detailed (and time intensive) analysis of changes in species composition in small plots for a selection of habitat types.

Updating EuroMove

The present result can be used to update EuroMove by 1) adding more species (especially species from the Netherlands for which detailed data are available), and 2) incorporating information on the dispersal ability of individual species.

Up-scaling towards Europe

The up-scaling towards Europe is probably very time consuming since for the species that are not covered in Atlas Flora Europaeae (and thus EuroMove) no detailed Europe-wide distribution data are digitally available. A feasible starting point might be the usage of the approach taken in the present project for species that are already covered in Atlas Flora Europaeae.

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