Water and biodiversity in the future climate

Work package leader : Prof. dr. ir. J.P.M. Witte

Content

1 Description work package

1.1 Problem definition, aim and central research questions

Problem definition

Climate change leads not only to higher temperatures, but also to changes in precipitation and evapotranspiration. In the Netherlands, summer droughts are expected to occur more often and last longer whereas rainfall is expected to be concentrated in intense showers. These meteorological changes will not only alter the water balance of the soil-water-vegetation system, but will also affect habitat factors essential for plant growth such as soil acidity and the availability of moisture, oxygen and nutrients in the root zone of plants. Furthermore, vegetation will likely feedback on climate change by adapting characteristics that determine actual evapotranspiration like rooting depth, vegetation cover and water use efficiency. All things considered, climate change will presumably result in large alterations to both water balance components and vegetation composition. Changes in temperature and the spatial configuration of vegetation types will determine the chances of plant and animal species to migrate through the landscape and find new habitats to survive.

Given the above-mentioned climate and water-related changes, it is questionable whether European nature targets (Bird Directive, Habitat Directive and the Water Framework Directive), obligatory by law, may still be attained under future climate scenarios. Similar concerns apply to the nature protection aims formulated by nature management organizations. An expedient response to climate change through adaptive measures in policy, water and nature management can eliminate potential threats and create opportunities for nature development. Potential measures include different planning of nature targets in the National Ecological

Network (EHS), the creation of hydrological buffers against desiccation, water storage in aquifers during wet periods (ASR), the extension of protected areas to increase the chances of successful dispersal for plant and animal species, and the spatial planning of ecological networks.

Aim

Our central aim is to assess the effects of climate change and adaptive measures - by policy makers, nature managers, and farmers - on the conservation values in the rural landscapes of the Netherlands.

Central research questions

- What are the effects of climate change on the water cycle, on vegetation biodiversity, and on the ecological networks of plants and animals? (project 2.1)
- How does vegetation biodiversity respond to climate change? (project 2.2)
- What are the future effects of inundations − be it natural or planned, to prevent flooding down-stream − on the vegetation of stream valleys? (project 2.3)
- What are the effects of climate change on the ecological networks of plants and animals (project 2.4)?
- What are the perceptions of natural resource managers of nature conservation, what are their goals, and how do they intend to achieve these goals? (project 2.5)
- Which adaptive measures in policy, nature and water management are feasible options to help eliminate potential climate change threats and create opportunities for nature development? (all projects)

1.2 Interdisciplinarity and coherence between the projects

This work package will be carried out in close co-operation with stakeholders as they are responsible for the hydrological modeling of the case study areas. Using distributed hydrological models, they will provide the work package with the hydrological variables necessary to forecast effects of climate change and adaptive measures. This will be done for each scenario – policy option combination generated by WP1, and for three characteristic weather years. Necessary variables should be high resolution (preferably 25m or less) and include daily values of groundwater depth, moisture content, seepage rate, etc. For a climate-versatile prediction of hydrological variables, project 2.1 provides the distributed model with knowledge of how evapotranspiration characteristics of the vegetation and crops will adapt to climate change.

We are convinced that changes in plant communities as a result of climate change, mainly occur through changes in both temperature and in water balance components. This conviction is based on sound scientific research (e.g.: Bazzaz et al., 1996; Knapp et al., 2008; Van Oene & Berendse, 2001; Van Walsum et al., 2001; Witte et al., 2009; Bartholomeus et al., submitted). New diseases and invasive species may also play an important role is shaping species communities. However, invasive species are especially a nuisance when they come from other continents, like North America (e.g. *Prunus serotina*) or Asia (e.g. *Fallopia japonica*) and potential problems related with such aggressive invaders is not a topic that specifically relates to climate change research.

Using the outcomes of the hydrological models as input, as well as information on soil, land use and atmospheric deposition of nutrients, project 2.2 enables us to assess the effects on vegetation biodiversity. In stream valleys, however, the predictions will be hampered by the fact that little is known about the ecological effects of flooding. Project 2.3 aims at providing sufficient knowledge about these effects, as well as with the effectiveness of catchment scale adaptive measures such as ASR.

Climate change stimulates plant and animal species to find new suitable habitats in the landscape. To protect species from extinction, these habitats may also be planned and created. The functioning of current and planned ecological networks is researched in project 2.4. To accomplish this, the projections of future vegetation that were calculated in projects 2.2 and 2.3 will be used. Project 2.5 starts by identifying the goals of decision makers and managers concerned with nature. These goals and the foreseen adaptation strategies of the various nature managers will be fed to the agent-based model in project 1.2.

1.3 Stakeholders

See Section 4B.

2 Project 2.1 The future groundwater recharge: evapotranspiration of natural vegetation to climate change

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2.1 Problem definition, aim and central research questions

Problem definition

Climate change will affect the amount and temporal distribution of both precipitation and evapotranspiration (ET). In the Netherlands, summer droughts are expected to occur more often and last longer, and rainfall is expected to be concentrated in more intense showers (Van den Hurk et al., 2006). These changes will alter the amount of water that percolates to the saturated zone, the groundwater recharge (R), as well as the size and dynamics of fresh groundwater bodies. Moreover, in the coastal (dune) areas, the groundwater recharge is crucial to the maintenance of the freshwater bell and the dynamics of the fresh – salt interface. Fresh groundwater is a prerequisite for many land use functions in the Netherlands: ecosystems with high conservation values are often confined to places with shallow groundwater, especially when fresh and alkaline groundwater exfiltrates at the soil surface; high groundwater tables supply agricultural crops with water via capillary rise and; the major source of drinking water in the Netherlands is fresh groundwater.

Current knowledge, however, is insufficient to reliably estimate the effects of climate change on future groundwater recharge and freshwater availability (Wegehenkel, 2009). Future recharge can only be assessed if we understand how vegetation responds to changing climatic conditions and how these vegetation changes will feedback on R due to altered actual ET (Barr et al., 1997; Rodriguez-Iturbe &

Porporato, 2005; Tietjen et al., 2009; Wegehenkel, 2009). We expect that ET characteristics of vegetation will change as a result of climate change, especially on elevated soils with a low water holding capacity (sand and gravel). Current hydrological models do not account for these changes.

In an earlier study we showed that increased atmospheric CO_2 raises the water use efficiency of plants, thus reducing ET (Kruijt et al., 2005; Witte et al., 2006). In a later exploratory study we found another important feedback on dry sandy soils: the fraction of bare soil and non-rooting species (lichens and mosses) in the vegetation will increase when, according to projections, summers become drier (Witte et al., 2008). From provisional calculations it appeared that on the south slopes of dunes, which receive more solar radiation and are warmer than north facing surfaces, the fraction of vascular plants may drop from 70 to 20 percent in 2050 (KNMI scenario W+) due to increased moisture deficits. The ET of bare soil and non-rooting species is much lower than that of vascular plants and thus the vegetation consumes less water. However, this latter feedback needs further investigation.

Aim

The primary aim of our research is to improve simulations of ET and R in hydrological models in the context of climate change.

Central research questions

- How are solar radiation, temperature and soil water availability related to the cover fractions of plant functional types (PFTs) such as bare soil, mosses, lichens, grasses and shrubs?
- How do changes in cover fractions affect actual soil evaporation, transpiration and interception water loss?
- How does vegetation feed back on ET by changes in soil physical and soil chemical properties?

2.2 Approach and methodology

First, we want to know how vegetation and soil cover are related to soil moisture deficit. Field data (e.g. soil hydraulic properties, orientation, slope, and local meteorological conditions) will be collected at different sites in the Netherlands and abroad (ranging from south Europe to Denmark), covering a variety of environmental characteristics that could potentially affect soil moisture (climate region, succession stage, etc). We will record vegetation composition at each site and measure both above- and below-ground vegetation characteristics that are related to soil moisture such as cover, leaf area index and root distribution (Van Dam et al., 2008). Moisture deficits will be simulated with a recent version of SWAP that explicitly accounts for solar radiation on inclined surfaces. In order to acquire robust relationships that are valid under future climatic conditions (e.g. Bartholomeus, 2009), results will be related to PFT's and plant traits selected by moisture deficits, like stem specific density, cavitation resistance, plant height and root diameter (Cornelissen et al., 2003).

Second, we attempt to assess how soil cover and vegetation characteristics, as identified by PFT's and the traits mentioned above, feedback on the soil moisture conditions. It is increasingly recognized that in order to simulate ET correctly, each of the processes involved, i.e. soil evaporation, transpiration and water loss by interception, should be analyzed explicitly (Wegehenkel, 2009; Witte et al., 2008). Instead of traditional, correlative loss functions for transpiration, we will use a mechanistic approach that takes into account the water pressure differences between soil, plants and atmosphere, as well as heat characteristics (Brolsma et al., submitted; Porporato et al., 2001). This mechanistic 'systems analysis type' of approach can also be used to account for the influence of groundwater, as demonstrated by Vervoort & Van der Zee (2009). Lichens and mosses do not have leaves to transpire and lack a root system to take up water from the soil. Instead, they benefit directly from water intercepted by their tissue. The interception capacity of lichens and mosses will be measured by water addition, drying and weighing in the laboratory. Differences in ET and R between vegetation types will be deduced from observed time series of groundwater levels (Von Asmuth et al., 2001), lysimeters and natural tracers in groundwater, such as chloride concentration.

Third we want to simulate the development of PFTs and plant-physiological responses as a function of climate and soil development. Building upon previous studies (e.g. Brolsma et al., submitted; Tietjen et al., 2009; Wegehenkel, 2009; Witte et al., 2008), we pursue a dynamic model that allows analysis of the vegetation development on elevated sandy sites with different orientations and slopes and include the effects of temperature and water on organic matter content.
Predictions for the future climatic conditions of the Netherlands will be based on national climate scenarios and will be validated on field data abroad. The results of this research will be combined to improve the simulation of ET and R in hydrological models.

In addition to this PhD-project, KWR is willing to finance a post-doc project on the same topic as well as additional staff costs. Results from this extra work will contribute to this project and its success. The project will be closely linked with PhD projects 2.1, 2.2, 3.1 and 3.3 of KfC proposal 'Climate proof fresh water supply'.

2.3 Scientific deliverables and results

The proposed research will result in at least four scientific papers about:

- Process-based relationships between drought stress and the ET characteristics of vegetation
- Explicit simulation of water loss by interception for different vegetation types
- A dynamic model to simulate vegetation and soil development, ET and recharge on elevated sandy soils
- A climate-proof ET procedure or correction factors for hydrological models

2.4 Integration of general research questions with hotspot-specific questions

Many hotspot questions deal with the availability of fresh water, especially in summer, for nature, agriculture, drinking water and other land use functions. To properly address these questions, quantitative knowledge about future evapotranspiration and groundwater recharge is a prerequisite. To supply the other projects within this theme on time with required information, we will first put our efforts on assessing correction factors for ET by analyzing relationships of observed vegetation characteristics and moisture deficits (i.e. the first two research steps mentioned in section B). Results of the dynamic model (third step) are expected at the end of the project.

2.5 Societal deliverables and results

Insufficient knowledge on the climate change effects on future vegetation composition and the involved feedbacks on the freshwater availability is among the weakest points of hydrological modeling. Robust models, however, are indissoluble for reliable predictions of future water availability for drinking water, agriculture and nature, and for sufficient adaptive water management strategies. This project aims at climate-versatile hydrological modeling with the final aim to identify climate change threats for future freshwater availability in order to facilitate timely adaptive water management strategies. Results will for instance be used to determine if there is a risk of not achieving NATURA 2000 goals, or to explore water management options to ensure enough drinking water in hot summers and an economic sound agriculture.

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3 Project 2.2 A spatial and climate-robust model for vegetation biodiversity

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3.1 Problem definition, aim and central research questions

Problem definition

Climate change will alter the diversity of plant species and plant communities through changes in temperature and in the water cycle (Bartholomeus et al., 2009; Knapp et al., 2008; Witte et al., 2004). In turn, these alterations will affect habitat factors essential for plant growth such as salt levels and acidity as well as the availability of moisture, oxygen and nutrients. As a consequence, it is questionable whether the nature targets obligatory through European law (Bird Directive, Habitat Directive and the Water Framework Directive) can still be attained in future climatic conditions. A timely response to climate change through adaptive measures in policy and nature management can eliminate potential threats so that opportunities for nature development may be created and targets fulfilled.

Habitat distribution models (HDMs) play an important role in evaluating the effects of climate change on vegetation composition (Guisan & Zimmermann, 2000). Current HDMs, however, are likely inapplicable under changing climatic conditions for a number of reasons. First of all, they use relationships based on measurements from the current climate assuming steady state conditions. Upon climate change, steady state conditions will no longer apply and various studies have indicated that upon such conditions other processes may become important, including adaptation, shifts in feedback mechanisms and the occurrence of different limitations. Second, the applied relationships between environmental factors and vegetation characteristics are highly correlative and do not include climate variables like temperature, which impedes application to other climatic conditions (Botkin et al., 2007; Guisan & Thuiller, 2005; Pearson & Dawson, 2003). Third, they do not account for no-analogue combinations of environmental conditions (Bartholomeus et al., 2009). Finally, current HDMs do not account for feedback mechanisms with the environment, a critical feature upon non-steady state conditions. Explicitly incorporating more mechanistic links between the environment and vegetation will make HDMs more valid under changing climatic conditions (Kearney & Porter, 2009).

Aim

The aim of this project is to develop a climate-robust HDM, applicable to a variety of spatial scales and the specific needs of stakeholders in the Netherlands.

Central research questions

- Can we make relationships between habitat factors and vegetation climate versatile and which parameters are most suitable to derive such relationships?
- What are the accumulated effects of uncertainties in input variables and model relationships?
- Can we account for feedbacks from vegetation on soil development?
- What are the effects of climate change and adaptive measures on vegetation biodiversity?

3.2 Approach and methodology

This project integrates knowledge from KWR and the VU Systems Ecology group as well as from three PhD-projects in the BSIK-project A1 (*Biodiversity in a changing environment: predicting spatio-temporal dynamics of vegetation*) (e.g. Bartholomeus et al., 2009; Douma et al., submitted; Ordoñez et al., 2008; Ordoñez et al., in press; Witte et al., 2004; Witte et al., 2007) into a climate-robust model for nature targets. The post-doc position will be substantially supported by KWR personnel on ecological modeling and on the use of GIS and software development.

Our model will have two important novel features. The first is the explicit use of plant traits on a continuous scale in order to make predictions robust (Violle et al., 2007) while at the same time avoiding the disadvantages of plant functional types (PFTs) (e.g. there is a clear mismatch between the a priori defined PFTs as discrete classes and continuously varying vegetation responses and effects). Plant traits, like leaf nitrogen content, litter decomposability or maximum relative growth rate, are continuous, they provide the direct mechanistic response of vegetation to soil and climate, allow adaptation and directly describe vegetation-atmosphere feedbacks. Because plant traits are linked directly to the environment, no assumptions have to be made about steady state conditions. In recent years, various publications have experimentally proven that functional approaches based on traits are more robust than species-based approaches.

The second novel feature is the use of a database with over 35,000 vegetation records. This large database enables us to reliably describe the Bayesian occurrence probability of vegetation types as a function of plant traits for any vegetation classification system the stakeholders desire (Witte et al., 2004; Witte et al., 2007).

To obtain model predictions, at least three steps will be taken. In the first step, habitat factors that directly influence plant life, such as the availability of oxygen in the rootzone of plants (Bartholomeus et al., 2009) or the release rates of nutrients, will be modeled in a mechanistic manner that takes climatic variables into account. Second, with the aid of robust relationships between these habitat factors and plant traits, future plant traits will be established. Robust relationships are derived by using ecological and ecophysiological knowledge to link traits, known from plant strategy concepts to respond to particular habitat factors, to those habitat factors. Finally, the occurrence probabilities of vegetation types, like those identified as target types by stakeholders, and vegetation attributes such as the percentage of endangered species will be computed, given the land use and land management maps created by the ABM in project 1.2. The resulting vegetation distributions will be fed back to the ABM so that the there simulated nature managers may adjust their actions. To avoid systematic errors resulting from differences between measured and modeled habitat factors, the relationships of step two could also be based on modeled habitat factors and geographically well located vegetation records, provided that the study area has been modeled accurately and in sufficient detail. In order to judge model predictions properly, we will investigate how errors in input variables and model relationships propagate.

3.3 Scientific deliverables and results

To supply the other projects on time with required information, model development will take place in three successive stages. In the first year we will issue a model version based on existing simple soil chemical decision systems (e.g. Runhaar et al. (2002)). In the second years, we will incorporate a mechanistic soil chemical model (e.g. based on Century; Parton et al. (1987)) as well as error propagation. The third version will try to account for feedbacks between vegetation and soil development. Feedbacks to the water cycle are especially relevant for dry sandy soils and will be accounting for applying knowledge from project 1.1. Feedbacks to the nutrient cycle, e.g. changes rates of nutrient release through productivity and litter quality, will be incorporated integrating knowledge from other sources.

In close co-operation with the stakeholders, the model will be used to assess the effects of climate change and various adaptive measures in a number of case studies.

Currently, no HDM exists that accounts for plasticity in vegetation characteristics of the species involved (e.g. due to differences in habitat conditions or direct adaptation processes), nor do models exist that evaluate error propagation and only a few models have some kind of feedback mechanism involved. Therefore, it is expected that this research will produce at least two publications in an international peer-reviewed journal and two trade journal publications.

3.4 Integration of general research questions with hotspot-specific questions

Assessment of the vulnerability of our nature has been identified as a key issue by various stakeholders. Stakeholders have also repeatedly indicated that an important unknown is whether the habitat in the Netherlands will remain suitable for particular flora and fauna groups (also in relation to e.g. the obligations as formulated in the Habitat Directive and Natura 2000). Reliable predictions of future nature targets are therefore a prerequisite to properly judge adaptive measures such as ASR, reshaping drainage systems and the integrative application of nutrient management measures, like grazing, mowing and sod-cutting. In close co-operation with the stakeholders, we will develop tailor-made model versions for each specific regional case study.

3.5 Societal deliverables and results

The knowledge generated by our research will be used to identify areas that are or may become or may be threatened to continue to be hotspots of plant biodiversity in the Netherlands under various scenarios of climate change and water management. This will allow optimal spatial planning in order to conserve and enhance biodiversity under various scenarios of climate change. Ultimately, this information supplies Dutch organizations responsible for the conservation of nature (e.g. water boards, governmental bodies, nature conservation organizations) with spatially explicit information to evaluate, conserve and create biodiversity.

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4 Project 2.3 Optimization of water storage in stream valleys in the elevated cover-sand landscape with respect to nature, agriculture and water supply

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4.1 Problem definition, aim and central research questions

Problem definition

The stream valleys in the elevated cover-sand landscape of the Netherlands are a typical example of multifunctional landscape types. They are important for agriculture, nature and recreation.

Climate change predictions for the Netherlands include the occurrence of warmer and drier summers and increased frequency of heavy rain showers. These changes affect the quantity and quality of fresh water for several land use functions (or even for drinking water supply). Potential adaptation strategies include:9

- The use of stream valleys for the storage of surplus water by upstream storage in local depressions, e.g. by weirs or by increased meandering (‘storage at the source’);
- Storage in the subsurface of cover-sands and glacial ridges (via ASR or more naturally by restoration of the natural infiltration hollows and fens on the catchments’ divide by removing artificial drainage systems);
- Increase of groundwater recharge through changes in vegetation or crops (with plant species that have lower transpiration rates, cf. project 1)

These measures will lead to positive changes in the quantity of surface water (mitigation of discharge peaks as well as summer low flows) and improve both the quantity and quality of groundwater by increasing upward seepage. This has a direct effect on the intensity, the dynamics and the quality of the water that discharges on the brooks.

In turn, the adaptation strategies will also affect the feasibility of nature targets in stream valleys (Van Bodegom & Aerts, 2006). These effects occur in combination with the direct effects of predicted climate changes, i.e. higher average temperatures and more extremes in temperature and precipitation, the latter leading to more discharge peaks in stream valleys. This will lead to increased flooding of the stream valley vegetation, especially in the middle and lower course. Although adaptation strategies partly diminish discharge peaks in the lower course, the subsequent inundation of upstream brook valley vegetation probably has negative effects on the vegetation if the stream water is enriched with nutrients (Aerts et al., 2003; Bartholomeus, 2009; Beumer, 2009; Van Bodegom et al., 2006a). These negative effects will mainly occur in nutrient-poor vegetation and during the summer period. On the other hand, there are sufficient indications that inundation can mitigate the natural acidification of stream valley substrates and as such be favorable for stream valley vegetation (e.g. Stuurmans et al. 1997).

Our knowledge of the hydrological requirements of stream valley vegetation is very limited. The only information available is the correlation between inundation frequency or inundation duration and vegetation type (e.g. Van Bodegom et al., 2008) or expert knowledge (e.g. Werkgroep WNNB, 2007). Due to this knowledge gap it is not possible to predict the effect of increased seepage, inundation in a warm summer or the effects of climate change (Van Dijk et al., 2007).

Thus, we do not know the impact of water storage in stream valleys, in combination with climate change, on biodiversity in nature areas and if there will be side effects on the surrounding agricultural landscape. Moreover, we do not know if the current spatial configuration of landscape elements is optimal for high biodiversity. On the other hand, there are also several opportunities to make use of these changes. Possibly, water storage of neighbouring areas can be used to sequester more atmospheric carbon dioxide and as such to create a new carbon sink (Aerts & Ludwig, 1997; Bakker et al., 2006). Moreover, the stored water can also be used as a new opportunity for freshwater supply, because the recharge of the ground water can also stimulate the economic use of this water. In addition, the water that is stored in wet periods can also be used as a buffer for dry periods. Finally, increased groundwater recharge, either naturally by climate-change through more precipitation and less vegetation or artificially by removing upstream water courses, may possibly enhance both the quantity and the quality of summer low flows and valley groundwater.

Aim

The aim of this project is to investigate how we should configure the spatial arrangement of landscape elements in stream valleys to optimize biodiversity under various scenarios of water storage and climate change.

Central research questions

- How to adapt correlations between biodiversity and abiotic conditions to predict the effects of water storage and climate change on biodiversity?
- How robust is the calculated spatial arrangement against the increase in weather extremes, as predicted in climate scenarios?

- Can we develop a method that can predict if the aforementioned changes also offer opportunities for new types of nature?
- Can water storage be used to increase the supply of drinking water both in the brook valleys as well in the groundwater system by both climate-induced and artificially enhanced upstream groundwater recharge?
- Is this water storage sufficient for supplying extra water for nature and agriculture during droughts?
- Can we use water storage and the accompanying rewetting of ecosystems to store more atmospheric carbon and as such contribute to the Kyoto obligations?

4.2 Approach and methodology

To determine the optimal use of stream valleys with respect to biodiversity and to determine how we can better utilize stored water for nature and agriculture, we will use a three-step approach:

- To answer the central research questions, we will include the effects of water storage in the stream valleys on local hydrology in current hydrological models. Also measures to artificially enhance groundwater recharge in the upper parts of the catchment will be included in existing hydrological models (Van Loon et al., 2009a; Van Loon et al., 2009b; Werkgroep WNNB, 2007). Model runs with and without these proposed measures will provide the hydrological effects of adaptation strategies. These will be coupled to vegetation models to calculate the effects on biodiversity. These vegetation models are built upon the database of dr. Runhaar on the correlations between abiotic circumstances and current biodiversity (Werkgroep WNNB, 2007) and upon trait databases of wetland plant species of dr. van Bodegom in combination with plant physiological and ecological concepts to derive process-based and climate-proof relations between botanical diversity and abiotic circumstances at various moisture levels (Brolsma et al., 2009; Van Bodegom et al., 2006b). Within these models, the effects of expected very wet and very dry extremes will also be included. As the models of dr. Van Bodegom are based on plant-traits and not on plant species, they can also be used to predict if we can expect new types of nature under various combinations of water storage and climate change. A combination of hydrology and vegetation models will subsequently be used to create ‘artificial landscapes’ in which the spatial arrangement of various landscape elements can be varied and we can calculate how this affects nature values and agricultural production to derive an optimal spatial configuration.

- To validate the vegetation models, we will make an inventory of the current relation of spatial landscape configuration, biodiversity and hydrology in a number of stream valleys in the eastern and southern part of the Netherlands. From this dataset we will determine how these elements are related in the current situation and validate the relations between wetland plant traits and hydrological features.

- To answer the central research questions, we will determine, based on model calculations, if storage water can be used as drinking water, to stimulate the development of carbon-accumulating ecosystems, and to supply both nature and agriculture with water during dry periods.

4.3 Scientific deliverables and results

This project will provide new insights into the combined effects of man-induced upstream and downstream water storage and climate change (including extremes) on biodiversity. This is a new line of research and will undoubtedly result in some highly relevant publications. Moreover, by not only focusing on biodiversity but also on other ecosystem services (water supply for nature and agriculture, buffering of extremes, carbon storage, drinking water supply) this project offers a multi-faceted approach to landscape planning in a changing climate.

Furthermore, this project will provide data on biodiversity changes of brook valley vegetation in response to maninduced upstream and downstream water storage. So far, we do not know how these measures will affect biodiversity of these important ecosystems. In addition, we will also show how climate change (and notably climatic extremes) will affect biodiversity of these ecosystems. These scientific results, primarily published in ecological journals, can be used by policy makers and nature conservancy organizations to optimize future landscape planning projects. As the project will also deliver scientific results on the effects of man-induced and climate induced changes on other ecosystem services (water supply for nature and agriculture, buffering of extremes, carbon storage, drinkwater supply) the results of this project can also be used by policy makers and managers of provinces, nature management organizations and agricultural organizations. As such, these scientific results will increase the costeffectiveness of landscape planning activities in the Netherlands.

4.4 Integration of general research questions with hotspot-specific questions

This proposal has a strong basis, combining various aspects that play an important role in the practices of stakeholders and that responds to questions raised by provinces (e.g. of Gelderland, Drenthe and Noord-Brabant) and nature management organizations. By coupling nature values to landscape planning and water supply, costeffective adaptation strategies may be developed for the good of all stakeholders involved. The project will result in a paper in a Dutch journal read by various stakeholders. Results will be disseminated through workshops with stakeholders of KfC.

4.5 Societal deliverables and results

This proposal will generate important knowledge for policy makers and managers (provinces, nature management organizations, agricultural organizations) within the following areas:

- Information about the locations that offer the greatest and probably cheapest way to realize certain nature targets with high biodiversity.
- Well-founded decision-making about the spatial planning of nature and agriculture, also in a changing climate.
- Possibilities of creating ‘new nature’ with vegetation types that do not occur yet in the Netherlands, but that will thrive in a changing climate.
- Possibilities to use excess water through ASR and artificially enhanced groundwater recharge for drinking water supply or for mitigating the effects of drought.
- Investigating the possibilities to create ecosystems that store more carbon.

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5 Project 2.4 Adaptation strategies for ecological networks; quantifying spatial adaptation measures to compensate for additional population fluctuations and to facilitate species range shifts

Project leaders: Dr. C.C. Vos, Dr. A. Van Teeffelen and prof. dr. P.F.M. Opdam

5.1 Problem definition, aim and central research questions

Problem definition

The National Ecological Network (EHS) is a spatial strategy for protecting biodiversity in landscapes with high pressure on land use. Based on metapopulation theory (Hanski et al., 1996), it implies that while single nature sites are too small, species can survive in a network of sites with sufficient size and connectivity (Opdam et al., 2003). The habitat network concept is the foundation of the European Natura 2000 network.

Climate change affects biodiversity in ecological networks (Opdam and Wascher 2004). A direct effect is that species distributions do not follow the shifting climate space due to too large discontinuities in the habitat configuration (Devictor et al 2008, Vos et al. 2008). Another direct effect is due to the increase of extreme weather events. Although little is known of impacts of increased weather variability, theory predicts that large scale synchronized disturbances, such as periods of extreme drought, increase population fluctuations and regional extinctions (Akcakaya & Baur, 1996; Piessens et al., 2007). Indirectly, climate change affects biodiversity through changing abiotic conditions, resulting in current habitat locations becoming unsuitable, while opportunities for habitat restoration arise elsewhere (see other projects within this WP). Adaptive measures for other land use functions (e.g. water management, farming) may also change the spatial functioning of habitat networks.

This has raised the question whether and how habitat networks should or can be adapted to facilitate climate-induced range shifts or mitigate effects of weather extremes. Such adaptation is legitimated from the point of view of protecting species, but also to maintain adequate levels of functional biodiversity to maintain the adaptive capacity of ecosystems to provide ecosystem services (Hooper et al., 2005). Here we consider three ways to adapt the spatial cohesion of the EHS-network. Firstly, to facilitate predicted range shifts, regional habitat networks could be better connected to create connectivity at the level of scale at which climate zones are shifting (Vos et al., 2008). Secondly, to mitigate increased population fluctuations, the minimum network size required for a certain level of biodiversity could be raised (Verboom et al., 2001). Thirdly, accommodating for both range shifts and increased population fluctuations, the density of (semi)natural elements in the landscape surrounding protected nature areas and corridors could be raised (green infrastructure) (Ricketts, 2001, Grashof-Bokdam et al., 2009).

At the national and provincial policy level, the necessity and feasibility of these adaptation measures are being discussed, as well as the level at which biodiversity in ecosystems should be maintained. Progress in science thus far does not provide quantitative guidelines for spatially adapting habitat networks in relation to desired ambition levels of biodiversity. In relation to this, the effectiveness of the three adaptation options in the specific land use context of a region can not be compared. With this proposal we aim to contribute to filling this gap.

Aim

To quantify adaptive measures to increase the adaptive capacity of ecological networks under a climate change regime, in relation to variable ambition levels for species diversity, and with emphasis on the comparative effectiveness of implementing the three adaptation strategies in a multifunctional regional context.

Central research questions

- What is the impact of extreme weather events on the survival of species in ecological networks, and which are the consequences for the minimum required network size which is currently assumed in Dutch spatial planning?
- How can green infrastructure in the multifunctional landscape mitigate population effects of weather extremes and facilitate species to follow their shifting climate zone?
- How can we effectively build adaptive capacity of ecosystem networks by spatial adaptation strategies in the variable context of different regions and with variable ambition levels of biodiversity?

5.2 Approach and methodology

Although the progress in understanding how landscapes can accommodate range shifts provides a sufficient basis for quantifying adaptation scenarios, the understanding of the relation between weather extremes and landscape structure needs more basic work.

Weather extremes and minimum network size

We build upon existing spatially explicit individual based metapopulation models (e.g. METAPHOR and METAPOP; Verboom et al., 2001; Schippers et al., 2009). These models are for single species. To bridge the gap to the multispecies level required for spatial planning, we will model for a set of so called ‘ecoprofiles’ (Vos et al 2001), i.e. model species representative for a range of variation among species in required habitat area, distances between habitat patches that can be bridged on dispersal, and sensitivity to environmental stochasticity. Ecoprofiles can be arranged according to an increasing ambition level of conservation efforts (Opdam et al., 2008).

For each selected ecoprofile, we explore the impact of increased weather variability on metapopulation survival for a range of spatial dimensions of habitat networks. We choose plausible weather time series (generated by the KNMI) that fit within the selected climate change scenarios (see project 1.1). Model outcomes will be tested with a statistical analysis of time series of population data and extinction data, drawing upon results provided by a PhD in the A2 Klimaat voor Ruimte project (Cormont et al in prep) and by a PhD in a Kennisbasis KB1 programme (A. Malinowska).

The modeling will provide standards for minimum size of networks for sustainability which account for weather extremes, and allow negotiations for desired biodiversity levels in the regional planning process. Applying these new standards helps identifying areas which can be enlarged cost-effectively (e.g. in case study areas).

Green infrastructure

We use a recently developed method to identify spatial bottlenecks where the connectivity in the landscape is insufficient to facilitate range expansion (Vos et al. 2008). This new method combines projections of future climate envelopes based on climate change scenarios, spatially explicit land use maps from project 1.2 and a dispersal model that calculates connectivity between habitats in present and future suitable climate zones. The results of these calculations will be fed back to the ABM in project 1.2, so that nature managers' decisions may be influenced by the effects of the (changed) land use and management. Ecological profiles are modeled that represent existing variation in dispersal capacity and sensitivity for land use types. This results in a map (for instance for the case studies areas) showing where additional connectivity is most effective to facilitate range expansions.

We will also develop quantitative information about densities of green infrastructure required to mitigate the impact of weather extremes, as an alternative to extending the size of protected areas by buying land. We will use existing statistical models showing correlations between species occurrence and the distribution of small scaled and large scaled habitat networks (Grashof et al. 2009). Based on the relations found, we will develop spatially explicit standards for adapting habitat network by increasing the amount of green infrastructure in the surrounding multifunctional landscape.

Building adaptive capacity of ecosystem networks

We will use the case study areas to explore and compare combinations of adaptation measures to make visible the change in the capacity of ecosystem networks and their surroundings multifunctional landscape to facilitate adequate responses of biodiversity to climate change effects. We will design a set of spatial options and calculate the added value in terms of the improved capacity of ecosystem networks to maintain biodiversity levels under different climate change scenarios.

5.3 Scientific deliverables and results

The research will result in scientific papers on:

- The impact of extreme weather events on survival of species in ecological networks.
- Identifying bottlenecks in the landscape preventing the adaptive response of species to shifting climate zones
- Quantifying adaptation measures to mitigate the effects of weather extremes with green infrastructure
- Building adaptive capacity of ecosystem networks in different regional landscape settings.

5.4 Integration of general research questions with hotspot-specific questions

The results provide stakeholders in the case study areas with options to increase the adaptive capacity of ecological networks, and insight into the ecological effectiveness of these options in relation to variable biodiversity goals.

The adaptation options will form input for WP1. Spatially explicit adaptation strategies for climate proof networks will be implemented in the regional designs in project 1.3.

The different spatial distributions of land use and land management generated in project 1.2 will be evaluated for their effects on the functioning of ecological networks.

The integration of multifunctional adaptation is being coordinated in WP1. Integration of adaptation strategies will be explored by analysing to what extent water retention in stream valleys and the contribution of green infrastructure to farming systems will contribute to climate change proof networks.

5.5 Societal deliverables and results

The adaptation strategies developed in this project fit well with Dutch and European conservation policy. The EU recently published a 'White Paper' on climate change adaptation (Commission of the European Communities, 2009) proposing to enhance the EU's resilience to the impacts of climate change. Increasing the connectivity of the Natura2000 network is explicitly mentioned as a necessary adaptation strategy. Also multifunctional adaptation by improving the functional relations between nature areas and their surrounding landscape by green infrastructure is recommended.

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6 Project 2.5 Climate proofing management objectives and spatial planning of nature

Project leaders: Prof. dr. M.J. Wassen and dr. P.P. Schot

6.1 Problem definition, aim and central research questions

Problem definition

Climate change confronts nature management with a number of problems. The first is that climate change will change the physical nature of habitats. Species will migrate to follow the envelop of their preferred habitat, or perish when migration is not possible. Targets set for conservation at present nature areas may thus become unrealistic and outdated.

This creates a second problem, on how to set climate-proof nature conservation targets. One may aim at conserving the originally targeted species and spatially follow the suitable environmental envelop by designating new nature reserves at the optimal locations. Another option is to redefine, for the existing nature reserves, the targeted species suited to the new environmental conditions. Additional complexity is introduced by feedbacks between abiotic and biotic ecosystem components or between functionally connected species (van der Putten et al., 2004). Even when these fundamental scientific questions are answered, the practical feasibility of the chosen approach depends on possibilities of acquiring land to designate as new nature reserve, the (ir)relevance for nature conservation of species suited to the new environmental conditions in the existing nature reserves, etc.

A third problem is the multitude of actors in charge of nature management, land use and water management. They will have different strategies in dealing with climate change, also between specific geographic areas and individual nature reserves. Also their attitude towards cooperation with stakeholders in the rural area might differ (farmers, recreation, etc.). Thus conflicts may arise from different strategies with respect to nature conservation areas.

Finally there is the problem of the relative lack of coordination in spatial planning of, and setting targets for, nature reserves. It has been shown for instance that elaboration of species policy and spatial planning of the National Ecological Network (EHS) differs between Provinces (Glasbergen et al., 2002). Nonetheless, communication on this subject between provinces was hardly addressed. Loonen et al. (2007) showed optimizing spatial allocation of the EHS across provincial borders could decrease EHS boundary-length (as fragmentation proxy) by 30%, using only 50% of the area designated by the separate provinces. Clearly, coordination and optimization could significantly increase the efficient realization of nature areas and nature targets.

To foster the process of climate-proofing nature conservation policy and targets a new approach is needed, aiming at:

- presenting the effects of climate change on biophysical site conditions inside, and outside, nature areas;
- guiding and facilitating the process of actors re-defining nature targets and biophysical management.

Aim

Identifying the goals of nature managers and the corresponding adaptation strategies. In this way (i) the (current and future) adaptation policy instruments can be tailored to achieve maximum efficiency. Also, this project will generate information to feed the agent-based model in project 1.2

Central research questions

- What are the different perspectives of actors responsible for nature policy/management of nature conservation within the context of different scenarios and policy options?
- What is the attitude of these actors on cooperation with surrounding farmers?
- What type of information support is needed for all actors in the rural area to simultaneously enhance their communication/coordination, and effectiveness/efficiency in realizing nature goals under climate change?

6.2 Approach and methodology

The approach envisaged should entail both 'hard' scientific data and 'soft' process steering tools, together providing:

- A means of communication between the different actors, to coordinate their efforts towards target setting, physical management options and spatial designation of nature reserves, the EHS and other relevant ecological corridors;
- Guidelines on process management steps, aimed at structuring the cyclic interplay between policy making/target setting and consulting scientific information in databases, models, etc. for improved nature conservation efforts;
- Entrance to a central database with explicit spatial information, on elements relevant for redesigning nature conservation/management targets;
- Guidelines for ways of disclosing the, for actors, most relevant information from this database, which extracts from other scientific databases (e.g. Netwerk Ecologische Monitoring) and model simulations (e.g. Nature Planner, NHI, LandUseScanner, output from projects 2.1-2.4, etc.);
- (Spatial) optimization routines to significantly enhance the effectivity and efficiency of nature conservation and nature development under changing climate conditions.

A participatory approach involving actors and scientific experts is used to identify ways of bridging the science-policy gap. Interviews and structured workshops are used to analyze the information needs of actors and their way of formulating nature targets/management under changing climate conditions. Ways of presenting spatial nature-relevant data and biophysical changes under climate change are tested for two case areas in workshops, enabling direct feedback of actors.

The project makes use of, and integrates, the results of projects 2.1-2.4 concerning changes in biophysical conditions. The research group has ample experience in translating environmental changes to biophysical characteristics on regional/local level using linked 'sectoral' models and is internationally competitive in unravelling species interactions and feedbacks between ecosystem components (Rietkerk et al. 2004; Wassen et al. 2005). Further it has expertise regarding improving spatial planning support (Vonk et al., 2007; Dijst et al., 2005) and application of scientific knowledge to environmental policy making using cognitive mapping workshops with actors (Van Kouwen et al., 2009). The project addresses the need (Snyder et al., 2004; Van Egmond, 2008) for application of multi-objective optimization techniques to the complex task of spatial allocation, and strategy analysis using gaming approaches, by extending the work by Schot et al. (2005), Vink & Schot (2002), and Loonen et al. (2007).

6.3 Scientific deliverables and results

Re-evaluation of nature conservation targets in the light of climate change needs scientific underpinning, which presently is non-existent. Literature suggests natural resource management lacks a scientific evidence based and systems approach (e.g. Pullin et al., 2004; Bellamy et al., 2001). Moreover, the complexity and often contentious nature of setting conservation and management targets 'requires a process for transparent sharing of ideas supported by tools to visualize the collective understanding, providing an informed basis of dialogue and decision making' (Tidwell & Van den Brink, 2008).This project contributes to the scientific underpinning of nature conservation strategies under climate change conditions. It bridges the gap between science and policy by incorporating scientific knowledge into policy and management of relevant actors, based on the needs expressed by actors. It is innovative by scientifically analyzing the way actors take decisions on strategies and management and the information needed for that. It combines generic 'hard science' (theory, databases and models), work from 'citizen scientists' (Netwerk Ecologische Monitoring, Ecogrid) and local tacit knowledge of stakeholders and resource management actors, starting from the needs of local resource management actors.

Scientific deliverables

- increased understanding how to bridge the science-policy gap in the field of nature conservation;
- scientific underpinning of climate proofing management objectives and spatial planning of nature;
- international peer-reviewed publications.

6.4 Integration of general research questions with hotspot-specific questions

The hotspots are involved through the actors relevant for nature conservation/development, land use and water management. The will be interviewed concerning their needs, and involved in workshops enabling their reflection on the products presented and bring interactive workshops will serve as a communication tool for different actors in the hotspot areas to better coordinate and fine-tune their strategies and management initiatives.

6.5 Societal deliverables and results

The project provides an overview of converging and diverging approaches, and possible conflicts, for effective/efficient nature conservation/development in The Netherlands. It presents insight in information needs for developing future climate proof strategies.
The project also provides a framework for participatory spatial planning stimulating shared learning and effective communication between actors. This will enhance coordination which, together with spatial optimization tools, will lead to more effective and efficient nature conservation adapted to climate change.

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