CLIMATE CHANGE

SCIENTIFIC ASSESSMENT AND POLICY ANALYSIS

Assessing dangerous climate impacts for the Netherlands

Report
500102 007

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November 2006

vrije Universiteit amsterdam / IVM

International Centre for Integrated assessment and Sustainable development

KNMI

RIZA

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This study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change

Wetenschappelijke Assessment en Beleidsanalyse (WAB) Klimaatverandering

Het programma Wetenschappelijke Assessment en Beleidsanalyse Klimaatverandering in opdracht van het ministerie van VROM heeft tot doel:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

De analyses en assessments beogen een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. De activiteiten hebben een looptijd van enkele maanden tot maximaal ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse en zonodig buitenlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van de deelnemers van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Doelgroep zijn met name de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid.

De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit MNP, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het MNP is hoofdaannemer en fungeert als voorzitter van de Stuurgroep.

Scientific Assessment and Policy Analysis (WAB) for Climate Change

The Netherlands Programme on Scientific Assessment and Policy Analysis Climate Change has the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

We are concerned here with analyses and assessments intended for a balanced evaluation of the state of the art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to a maximum of one year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic. The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency, the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of the Wageningen University and Research Centre (WUR), the Netherlands Energy Research Foundation (ECN), the Netherlands Research Programme on Climate Change Centre of the Vrije Universiteit in Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute of the Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency as main contracting body is chairing the steering committee.

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Preface

This study was commissioned by the Netherlands Programme on Scientific Assessment and Policy Analysis (WAB) for Climate Change. The study has been coordinated by Joyeeta Gupta and Harro van Asselt at the Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

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List of Acronyms

ACIA	Arctic Climate Impact Assessment
AR4	Fourth Assessment Report of the IPCC
CAA	Clean Air Act
CO_2	Carbon dioxide
CZM	Coastal Zone Management
EPA	Environmental Protection Agency
GCM	General Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Greenland Ice Sheet
HOT	Helping Operationalise article Two
ICJ	International Court of Justice
IPCC	Intergovernmental Panel on Climate Change
IUCN	World Conservation Union
KNMI	Royal Netherlands Institute of Meteorology
MNP	Netherlands Environmental Assessment Agency
MPR	Maximum Permissible Risk
NGO	Non-governmental organisation
NLTCT project	Project on Re-evaluation of the Netherlands' Long-Term Climate Targets
SLR	Sea level rise
SRES	Special Report on Emission Scenarios of the IPCC
TAR	Third Assessment Report of the IPCC
TBE	Tick-Borne Encephalitis
TCI	Tourism Climatic Index
THC	Thermohaline Circulation
UNFCCC	United Nations Framework Convention on Climate Change
VROM	Ministry of Housing, Spatial Planning and the Environment
WAIS	West Antarctic Ice Sheet
WHO	World Health Organisation

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Introduction

In order to understand the urgency with which climate change needs to be controlled, it is important to realise the extent to which climate change can become dangerous for countries. The key question that we address is thus: How can Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) be elaborated into quantitative indicators for climate change control? Article 2 UNFCCC states:

> *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, (…), the stabilization of greenhouse gas concentrations in the atmosphere at a level that would* ***prevent dangerous anthropogenic interference*** *with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (emphasis added).*

Other relevant questions are:
- What operational criteria could be developed to indicate dangerous and non-dangerous levels of anthropogenic interference with the climate system?
- What indicators can be selected that are both politically relevant and publicly comprehensible and appealing, and that can be scientifically substantiated (attributable to climate change, reliable/valid, measurable, predictable)?
- How can different indicators be integrated?

In 1996, the Government of the Netherlands decided to interpret Article 2 as follows:
- The global average temperature should not rise above a maximum of +2ºC compared to pre-industrial levels;
- The rate of temperature change should be less than +0.1ºC per decade; and;
- Sea-level rise should be limited to a maximum of 50 cm (VROM, 1996: 88-89).

Subsequently, the European Council adopted a long-term climate policy goal to limit global warming to maximally 2ºC and a concentration level of 550 ppmv of CO_2 emissions (EC, 1996). These targets are subject to revision based on the latest information.
The earlier commitment of the Dutch Government in 1996 to interpret Article 2 proactively shows that within the Dutch political system there is a need for clarity regarding end goals. With the subsequent adoption by the EU of a goal in 2000, and by several other European countries,[1] the Netherlands is certainly not alone in the effort to better understand how the long-term target should be articulated. The Netherlands has also systematically requested assessments of the term dangerous climate change, and from that we infer that at least at the political level there is a need to be informed about the latest science in this field.
The question now is: Are these targets still valid given the new science available and to what extent is the underlying science anecdotal or based on substantial literature? This is a separate question from: Are these targets realistic?

In 2004, a team of Dutch researchers prepared an assessment of when climate change may become dangerous to the Netherlands (Gupta & van Asselt (eds.), 2004). However, there were many gaps in the assessment, and it was also unclear the extent to which the underlying information was based on anecdotal cases or was based on trends observed in the literature. Hence, the purpose of this project is to provide a more up-to-date assessment of an understanding of when climate change may become dangerous to the Netherlands.

[1] Namely Sweden, the United Kingdom and Germany.

Methodology

This report is not the result of new research. It is instead an assessment project, which means it merely assesses the existing scientific information available at this point of time. In other words, this report has a limited methodology. It should be noted, however, that the research builds further on the earlier completed assessment of when climate change becomes dangerous for the Netherlands. Three points about this assessment can be noted here. First, although some scientists see a definition of dangerous climate change as a futile exercise, we see it as a worthwhile endeavour, despite its shortcomings. Second, through identifying indicators, it is possible to work backwards through identifying threshold levels, temperature changes and concentration levels, and finally define acceptable emission levels. Third, although we build further on the results of a limited participatory integrated assessment, carried out in the previous round of a related project, this project merely updated the information and tested out the results at a national workshop.

Literature review on assessing dangerous climate change

A literature study of research undertaken to define dangerous climate change reveals a number of key issues:

- What is inherently clear is that defining dangerous climate change is something that is highly controversial. Many scientists deny that there is an objective method to define dangerous climate change and hence argue that the effort to do so is futile. Others argue that given the high degree of danger inherent in climate change, it is absolutely vital that efforts are made to define what constitutes dangerous climate change.
- Although there are a number of different methods used to identify dangerous climate change, most seek to only look at some part of the entire chain from impact through concentrations to emissions to the perception of the problem. Most authors identify indicators related to certain climate impacts but the identification of thresholds is difficult, as most impacts gradually increase with increasing temperatures. In such a case there are no clear thresholds. There is also considerable overlap between the indicators identified in the literature. Most articles focus on one or more indicators.
- Each discipline looks at danger differently and what is considered dangerous also differs between one person and another. In this report we try to indicate the reasons that can be given to consider a certain climate change dangerous or not.
- In the selection and assessment of indicators there are two kinds of risks. One, the choice of scale to determine risk is mainly national. At least most countries and researchers are studying this at national level. Only systemic impacts (i.e. large-scale events) are evaluated at a global level; almost all other impacts are seen purely from a national or local perspective. This may imply that impacts in other countries and regions are not taken into account to the fullest extent. The other issue is that there is a tendency to argue that since such risks are gradual, adaptation can play a major role. However, taking adaptation into account is not an easy exercise; and literature on adaptation demonstrates the numerous problems involved.
- Finally, several authors argue that a 2 ºC rise in temperature (or 400 ppmv CO_2-eq. Concentration level) from pre-industrial levels is the level at which dangerous climate change can set in because of the potential impacts of low-probability high-impact events. However, for many sectors and for abrupt and extreme events it is not clear if specific thresholds can be specified. Gradual change of our climate and gradual change of related impacts without a clear threshold temperature is more common. Therefore ultimately, the discussion on what is dangerous climate change, or in other words what are we willing to accepted as a society, will be determined in the political arena, on the basis of much more than only the scientific information.

Table 1. An ideal-typical assessment of how disciplines would deal with 'danger'.

Discipline	Focus	Explanation
Economics	Cost-benefit analysis	Such an analysis would reveal if the problem was dangerous; if the costs far exceeded the benefits to society.
Law	Liability; standards	Such an analysis would look at the causal chain; whether responsibility could de facto or de jure be ascribed to a legal entity; and whether current and future impacts were actionable. Standards could be used to determine what level of risk is acceptable to a society.
Ecology	Loss of biodiversity	Such an analysis would examine at what levels, populations, species, ecosystems and multiple ecosystems would be threatened.
International relations (neo-realist)	Power politics	Only if dangerous impacts are to be experienced by those in power, is action likely to be taken and then only to protect those in power.
Ethics	Ethical convergence	Such an analysis would look at the ethical concepts inherently related to 'danger' or 'risk. If all ethical theories come to the same judgment, there is a reason to adopt this judgment.

Source: Chapter 2.

Towards an updated Netherlands' perspective on dangerous climate change

An assessment of the state of the science on the climate system shows that given the multiple scales at which the climate change system functions, and the multiple positive and negative feedback loops, the future evolution of (regional) climate is subject to many uncertainties. These include the uncertainties regarding the development of anthropogenic activities, and related emissions of greenhouse gases and changes in land use; and limited understanding of the complex climate system; its inherent internal variability and its response to changes in concentrations of greenhouse gasses and land use changes. Nevertheless, the Royal Meteorological Institute for the Netherlands formulated four scenarios for the Netherlands. It is considered most likely that our future climate will develop between these four 'corner points' (see Figure 1 below).

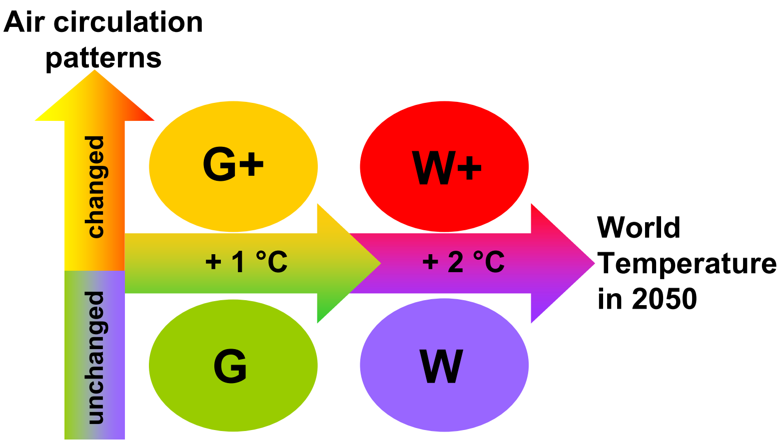

Figure 1. Schematic overview of the four KNMI'06 climate scenarios (for an explanation see the legend below).

Table 2. Legend for the KNMI'06 climate scenarios.

G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

* 'G' is derived from 'Gematigd' = Dutch for 'moderate'.

The implications of this for the Netherlands are:

Table 3. Climate change in the Netherlands around 2050[1], compared to the baseline year 1990[2], according to the four KNMI'06 climate scenarios.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter [3]	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer [3]	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

N.B. Footnotes to this table are not included here. Please see Chapter 3.

In general, projected changes have an increasing uncertainty when following the series of variables from temperature via sea level rise, precipitation and wind. Wintertime precipitation is more certain than changes in precipitation in summer. The mean changes are more certain than changes in extremes (events that occur once per 10 year or even less, and also 'abrupt' changes). This chain is partly dictated by the complexity of the underlying physical processes.
The gaps in knowledge include the circulation response of increased greenhouse gas concentrations; the dynamics of glaciers and large ice sheets; changes in precipitation at high latitudes; and the role of land surface interactions including snow and soil water.

Indicators of relevance to the Netherlands situation

The previous project identified 23 indicators on the basis of available literature and a workshop with a limited number of stakeholders. The indicators were chosen to be representative and scientifically sound for the assessment of climate change impacts in the Netherlands. Since the discussion on the assessment of the term 'dangerous' is closely related to public perceptions, an important criterion for the selection of the indicators was the appealing character of the indicator. Furthermore, it was decided not to present an extensive list of indicators, in order to keep the discussion transparent. In this project, the project team revisited the indicators on the basis of the new information available and concluded that the key indicators could be clustered along six key sectors for the Netherlands – namely fresh water, ecosystems, health, coastal zones, tourism and recreation, and agriculture. The impacts on industry (e.g. cooling water for energy generation) were captured under the above headings. It was also decided not to study economic impacts separately from the sectors, since that would lead to double counting. In addition, the team decided to include the threats posed by extreme events and abrupt events separately. Finally, during the stakeholder workshop in the previous project, some global indicators were seen also as critical to the Dutch cosmopolitan identity. Although these were not specifically investigated, it was decided to keep a generic category of international solidarity as an indicator.

Impacts on fresh water may require substantial adaptation

Four indicators in the area of fresh water were selected for this study, of which two are related to river discharge and two to precipitation. For river discharge these are design discharge and low flow discharge, as an indicator for navigation. For precipitation, these are the 10-day precipitation sum as an indication for waterlogging, and the precipitation deficit. The indicators stand for instance for the safety against flooding, access to and availability of clean water, navigation, and cooling water. The research indicated that due to climate change the river discharge is expected to increase in the winter and decrease in the summer. There is a likelihood that the regional water and the urban drainage system will have greater waterlogging problems, due to increasing precipitation. The Netherlands already experiences a minor water deficit in the summer months, and depending on the climate scenario the problems in the local system increase. Larger water deficits may result in serious problems for e.g. agriculture, ecosystems, etc. Due to lower river discharge and sea level rise it will be more difficult to discharge the river water in the North Sea. As a consequence there will be more salt-water intrusion, which threatens the fresh water supply for the regional water system and the drinking water supply. Due to the lower discharge of the Rhine in the summer, navigation will be negatively affected in summer months. Problems with cooling water for power plants will increase, because the water temperature will increase due the lower discharge and the increasing temperature. In order to reduce the risk of climate change the water system will need to be adapted to a climate change based on the +1°C temperature increase for 2050. In the case of flooding the adaptations consists of retaining and storing of water. However, there are also problems related to, for example, cooling water, where the adaptation has to be made by the sector itself. The above information is partly based on existing laws and policies, and partly on well-established scientific information, while some of the extrapolation is partly based on reasoning.

Ecosystems may not easily adapt

Indicators were selected for five elements of ecosystems that may be affected at a global, regional and local level. The elements include phenology, plants and vegetation, mammals, birds, and marine species. Indicators for each of these elements were assessed and these revealed that considerable impacts are already occurring now. Many show that species and ecosystems are able to cope with observed levels of climate change but some are detrimental. Beyond a 1-2°C warming, these detrimental impacts are expected to start to dominate and beyond a 2°C risks rapidly increase. This could become a major threat to biodiversity. The assessment of the recent scientific literature indicates that the Third Assessment Report of IPCC underestimated the climate change impacts on species and ecosystems. The terrestrial carbon balance would likely shift after a few decades from a sink into a source. This has serious consequences for managing atmospheric concentrations. There will be rapid phenological responses of plants and animals, widespread shifts in species geographic ranges, and changes in structure and composition of most ecosystems (not only in the boreal zone as previously stressed). There is now growing evidence for a high vulnerability of a considerable fraction of species becoming committed to extinction than previously assessed. Changes in disturbance and other stresses such as fires, invasive species and pollution are likely to exacerbate climate change impacts.

Endemic species (i.e. unique species confined to a small area) are very sensitive to climate change, resulting in clear impacts on biodiversity and biodiversity hotspots. The most sensitive ecosystems are coral reefs, Arctic systems, mountains, Mediterranean systems and savannas. In most cases, species persistence requires migration rates that exceed their natural adaptive capacity. These effects, combined with landscape fragmentation and pollution, limit natural adaptation, and increase their risk of extinction during this century. Marine ecosystems and species appear more able to shift range rapidly than many terrestrial species. All these impacts will lead to detrimental changes in ecosystem services. Impacts on sustainable development and livelihoods of people depending on the ecosystems remain, however, difficult to estimate.
The TAR already established in 2001 that beyond 2ºC global mean temperature increase compared to the pre-industrial level risks for negative impacts on species and ecosystems rapidly increased. This analysis shows that this assessment was too conservative. Risks for impacts on many local and regional species and ecosystems already rapidly increase beyond 1ºC global mean warming and are also not negligible at lower temperature increases.

To limit the risks for impact of climate change on ecosystems two approaches have to be taken. First, climate change has to be limited by limiting and reducing greenhouse gas emissions. This seems economically and technologically feasible. Second, the resilience of species and ecosystems has to be increased. One of the most effective strategies to achieve this is to reduce other stresses on species and ecosystems and enhance conservation efforts. However, the cascade of uncertainties from climate change projections through species to ecosystem responses remains a significant barrier to develop coherent and detailed regional policy planning.

Impacts on health

In the health sector, three indicators were chosen. These include increased mortality as a result of heat waves, increased risk of Lyme disease, and an increased risk of pollen allergies. Past heat waves in the Netherlands have resulted in an excess mortality of 38.9 excess deaths (12.8%) per heat wave day. However, part of the excess mortality during heat waves must be viewed as ‘only a slight forward displacement of deaths’. The other part of the excess mortality, however, relates to avoidable deaths and substantial loss of life. The most vulnerable to heat waves are senior citizens, persons with cardiovascular or respiratory disease, and young children. The view that climate change will have an impact on heat wave mortality is well established. Climate-change-induced heat wave mortality might become unacceptable under various assumptions regarding adaptation capacity and ‘forward displacement’.

The expectation that climate change has an impact on Lyme is well established, although more quantitative research is required. Tick densities are positively correlated with human Lyme disease. With less harsh winters, it is expected that tick survival, and, consequently, tick densities will increase. In addition, a significant prolongation of the tick-season is expected. If climate change would result in a (possible) 1% increase in disease incidence, the acceptable lifetime risk on morbidity – induced by climate change – might be exceeded.

Weather conditions affect the timing/duration of the pollen season, the quantity of pollen produced and the geographic distribution of flowering plants. However, the impact of climate change on allergic disorders is uncertain and there is a need to better understand this relationship between the changing climate and allergic disorders.

A wide range of adaptation options are possible which include legislative, technical, educational and behavioural changes that could enhance the ability of humans to overcome these risks. What is clear is that risks increase as temperature rises, but that adaptation may reduce these risks somewhat. More research on adaptive capacity is required.

Impacts on coastal zones will require substantial investment and adaptation

Having a long history of battling sea level rise, the Netherlands is well prepared to deal with the three indicators related to coastal zones.

- The first indicator is coastal squeeze, where a rising sea level leads to a shrinking of the coastal zones: Dune type of environments are thus gradually changed into more hard protection measures like dike systems.
- The second indicator is the risk of flooding. In order to maintain the current risk standards, major protection measures are needed against rising costs in case of higher sea levels. The same holds for the frequency and magnitude of exponentially rising costs in case of higher sea levels. Additionally a rising sea level brings with it a higher uncertainty. The reason for this is that the behaviour of the North Sea system induced by higher sea levels is not known from history. The same holds for the frequency and magnitude of extreme events like storms.
- Salt-water intrusion is the third indicator. Higher sea levels will cause salt surface water and groundwater to intrude further inland, impacting the freshwater supply and ecosystems. While in the short-term salt water intrusion can be prevented through membrane filtering techniques, in the longer-term, this may be difficult to deal with and drinking water inlets need to be moved more upstream.

Impacts on tourism and recreation may be beneficial

Not all the news is bad, as the story about tourism and recreation indicates. Climate change will generally have a positive influence on tourism and recreation in the Netherlands. Overall conditions for outdoor tourism activities (represented by the annual mean Tourism Climatic Index) will improve, and in summer, the period with very good circumstances will lengthen substantially, perhaps even by several months. One of the drawbacks of climate change for tourism and recreation in the Netherlands is the decreasing availability of natural ice in winter that is of sufficient quality for ice-skating. This trend is symbolised by the projected decreasing likelihood of the *Elfstedentocht* ice-skating events.

Impacts on agriculture

Three indicators were selected to represent the potential impacts on agriculture. These include a change in crop productivity, damage from extreme weather events and changes in commodity prices. Farmers are used to dealing with weather variability, a two degree temperature increase over the next century will not have a severe impact on the sector, as farmers will adapt. The direction and speed of development in the sector are strongly determined by economic and technological drivers. However, farming systems are vulnerable to extreme weather events and salt water intrusion. To which extent insurance remains a feasible option is unclear.

As the effects of climate for the Netherlands are relatively low when compared to other regions in Europe (e.g. southern Europe) current trends of intensification of agriculture in northern and Western Europe and extensification in the Mediterranean and south-eastern parts of Europe could be reinforced by climate change. These developments could have a positive effect on the competitiveness of agriculture in the Netherlands.

As the Netherlands is strongly engaged in commodity trade, impacts of climate change in other countries may raise the price of commodities affecting the market situation. In globalising and liberalising markets it will most likely result in shifts in production centres.

Extreme events

There is much speculation in the literature about the increased risk of extreme events following climate change. On the basis of the most recent analyses of KNMI it can be concluded that as a result of climate change:

- Temperatures, and related the chance of heat waves, will continue to increase;
- Precipitation in winter will increase, resulting in higher river discharges. In summer precipitation may increase slightly, or decrease clearly, resulting in hardly any change in river discharges or clear decrease. The intensity of extreme precipitation will increase in winter and summer;
- There is no indication that the intensity of gales in the Netherlands will increase clearly as a result of climate change.

Despite the small risk of extreme events in the Netherlands occurring, the financial and socio-economic consequences could be enormous. The possible impacts of these extreme events have been included in the sectoral indicators, e.g. agricultural damage from drought, increase mortality due to heat waves, and floods.

Impacts of low risk high impact abrupt events could be substantial and need to be avoided

A key problem is the potential of low-risk high-impact events that could change the shape of the climate – and the world – completely. Examples of low risk - high impact events are melting of large ice caps (Greenland, Antarctica), collapse of the thermohaline circulation, excessive release of carbon by melting permafrost etc. Most literature considers it unlikely that these events will occur in the 21st century at the temperature projections of the IPCC (+1.4 up to 5.8°C compared to 1990). Although, most consider the risk to increase with increasing temperatures (but still unlikely during the 21st century), no clear threshold can be given.

North-South solidarity

While many of the risks to the Netherlands may be manageable if the rate of change does not exceed certain thresholds, small island states and developing countries with coastal zones, and mountain zones are likely to be extremely vulnerable to a global mean temperature rise. There is very little literature to assess when solidarity thresholds can be crossed, but we did not consider that reason enough to not even mention this point.

Indicators and threshold levels

The following table attempts to sum up the information provided above in a comparative and simple manner. It indicates the type of indicator; the name of the indicator; and a brief description of the impacts for the Netherlands. It then uses a simple code to indicate how serious the impact can be; where a negative sign stands for a negative impact, and a positive sign for a positive impact. 0 stands for neutral. Where there will be autonomous adaptation – we indicate that with 'aa'. Where there needs to be proactive adaptation, we indicate that with 'pa'. Where systems become endangered, we show that through 'ed'. The term 'na' indicates not available. For a more extensive and nuanced description, see the various Chapters.

Table 4. Indicators and impacts relevant for the Netherlands at different mean global temperature rise compared to pre-industrial level (with and without adaptation).

Type	**Indicator**	**Description**	**+1º C**	**+2º C**	**+3º C**
Sectoral					
Fresh water	River discharge: design discharge	Higher winter discharge; increase of the design discharge	-	-	--
	River discharge: low flow	During the summer lower discharge, causing problems for navigations and power plants (shortage of cooling water), salt water intrusion	-	-	--
	Precipitation: 10-day precipitation sum	Waterlogging regional system; possible local water excess		-	--
	Precipitation deficit	Water shortage in the regional system		-	--
Ecosystem	Trees and plants	Physiology, phenology and distribution changes	-	-- Ed	--- Ed
	Mammals	Impacts on mammals	na	na	na
	Birds	Impacts on birds	-	--Ed	---Ed
	Marine species	Obvious in the North Sea, but also elsewhere in the oceans.	-	Ed	Ed
Health	Heat wave mortality	Mortality that can be attributed to heat waves	- aa/pa	-- pa	--- pa
	Lyme disease	Infectious disease spread by ticks	- pa	--- pa	--- pa
	Allergies	Increase in allergies because of pollinating season.	- na	-- na	-- na
Coastal zone	Coastal squeeze	Area between sea and coast shrinks	-	--ed	---ed
	Flooding	Increased risk of coastal flooding	0	pa	pa
	Salt water intrusion	Increased salt water intrusion	-	-- pa	--- pa
Tourism	Tourism climatic index	Tourism becomes attractive	+	++	+++
	Length of the outdoor recreation and tourism season	Recreation months increases	+	++	+++
	Frequency of the 11 city skating event	Frequency decreases	-	--	---
Agriculture	Crop productivity	Adapts to change in weather	0	-/+	-/+
	Damage from extreme weather events	Increase in magnitude and frequency	0	na	na
	Commodity prices	Price changes on world market → switching to other suppliers (countries), composition food products changes; could benefit the Netherlands	0	0/+	0/+
Systemic					
Extreme events	Frequency and intensity may increase		0/-	0/-	0/-
Abrupt events	WAIS, GIS could melt		na	na	na
Solidarity					
International solidarity		Water and food access may decrease; impacts of SLR on low-lying countries	0/-	-	--

N.B. The temperature rise is for global mean temperature rise since pre-industrial levels.

Communicating the information

The potential impacts of climate change on the Netherlands can be visualised as shown in the following figure. This figure updates and replaces the earlier figure entitled 'Perceived reasons for concern in the Netherlands' (Gupta & van Asselt (eds.), 2004). The following figure includes impacts on six sectors; irreversible systemic impacts; and international impacts that may concern the Dutch citizen. Text in bold indicates whether there is substantial literature pointing in a specific direction. As the colour turns from white through yellow to red, we expect that acceptable threshold levels will be crossed (when going from yellow to red). Although adaptation is possible in many areas, the cost of adapting increases as major thresholds are crossed.

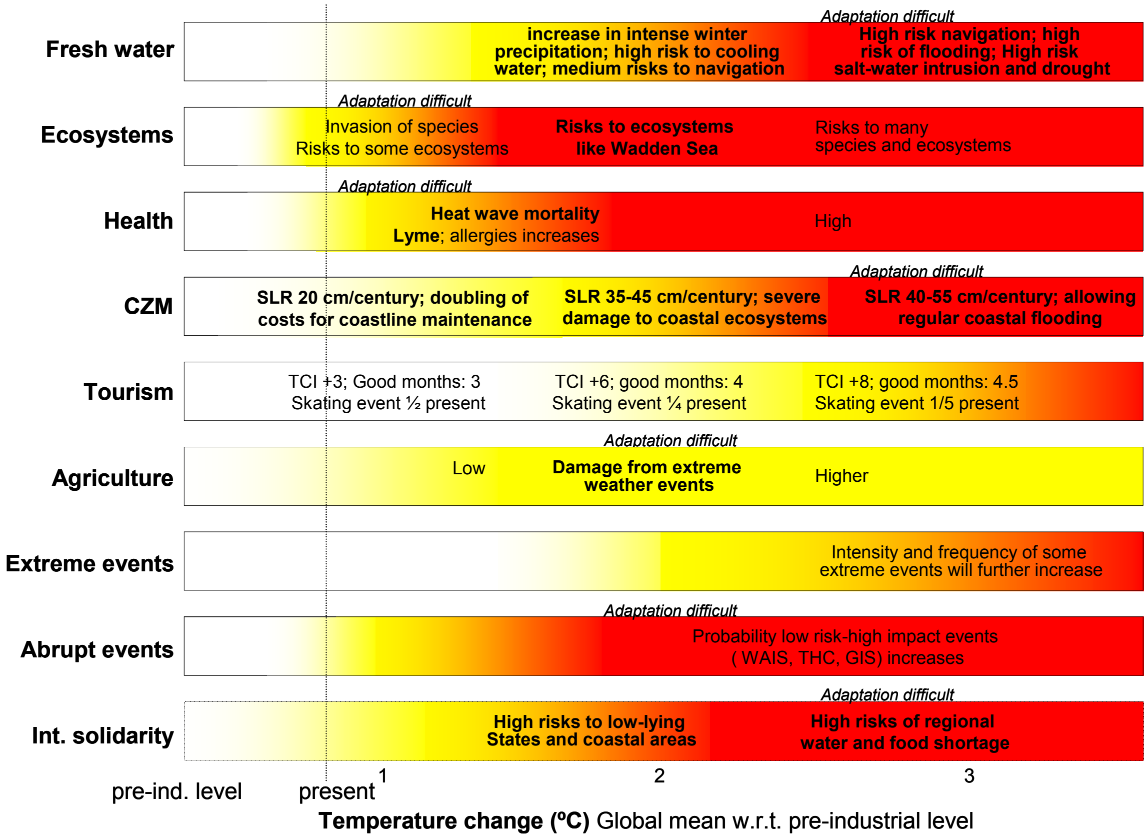

Figure 2. 'Burning Embers' figure for impacts relevant to the Netherlands (updated).

Clarification reasoning behind the 'Burning Embers':

- *Fresh water*: With increased temperatures the fresh water problems increase. The quantitative water sector aims at an adaptation based on a temperature increase of 1-2°C (compared to the 1990 situation), therefore compared with pre-industrial red starts between 2 and 3°C. Problems associated with drought and low flow can however already be problematic in an earlier stage.
- *Ecosystems*: Many changes are already observed in ecosystems. Many are adequate responses to cope with the changing climate but some are detrimental. The adverse impacts include the decline in population of migratory bird species and shifts in food webs in the North Sea. Negative impacts start to dominate beyond a 1°C temperature increase and increase in extent and magnitude beyond a 2°C temperature increase.
- *Health*: Health effects are expected with every temperature rise. Based on the lower threshold (i.e no increase in the chance of dying), climate change is only acceptable if adaptation will prevent all climate change induced heatwave deaths. Under a variety of assumptions (incl. adaptation), the upper acceptability threshold (i.e. acceptable annual risk

of dying= 10^{-6}) will be exceeded with a temperature rise of +3°C (compared to 1960-1990). Climate change is expected to increase tick densities (due to increased winter survival and prolongation of the tick season) and, subsequently, the risk on Lyme disease. The vast increases in tick-bites and Lyme disease in the past decade indicate that adaptation/prevention might be difficult. Even with a small an increase of 1% in the incidence of Lyme disease, the lifetime risk on morbidity due to climate change might become unacceptable. Climate-induced changes in pollen exposure may affect a large number of people, but there is insufficient quantitative information to predict the size of this effect.

- *Coastal zone management*: Major problems in the coastal zone for the coming 100 years are not foreseen. With higher temperatures, adaptation measures will become more drastic and urgent. However, this does not mean that we cannot cope with it. Sea level rise will have its impacts, but not to such an extent that we are surprised by it and that we cannot manage. Therefore, the colour sloping from white to red radiates and supports the message that developments and adaptations are gradually more drastic with rising temperatures.
- *Tourism and recreation*: In general, climate change has positive effects on tourism: outdoor conditions improve, and the 'holiday season' lengthens. Hence, no real dangers associated with 1 and 2 degrees increases in temperature. As a result of climate change, there will be fewer opportunities for ice skating on natural ice. As climate change intensifies, the likelihood of an *Elfstedentocht* ice skating event may decrease to around 20% of its current value, which is already low. This can be considered a loss of a traditional event in tourism & recreation, hence the orange score in the figure.
- *Agriculture*: Changes in Agriculture are largely driven by changes in markets and technology. Current systems will have to adapt to changes in climatic conditions. A gradual change, 4 degrees in 100 years, will not cause major problems for agriculture in the Netherlands. Key concerns are temporary water shortages and water excess which can result in yield reduction or even yield loss. Changes in climate extremes are a potential risk but so far climate scenarios present no clear picture on change in frequency and magnitude of extreme events such as late frost, hail, storms, etc. In conclusion agriculture will be able to adapt to gradual climate change but caution is needed in relation to extremes. Information on changes in extremes and the coping range of the sector is lacking to allow for quantitative conclusions.
- *Extreme events*: Starts with white since there were no or acceptable risk under pre-industrial conditions; between 1 and 2°C the intensity of some events (e.g. rainfall, length of heat waves may increase; it is not clear whether the frequency will increase) increases requiring adaptation, but adaptation is considered possible; red at the right end (about 2°C compared to current situation): adaptation is still possible but more costly. Thresholds may be passed if no adaptation takes place, but this is not clear.
- *Abrupt events*: Starts with white since there were no or acceptable risk under pre-industrial conditions; red at the right end (and gradual change in between): although the risk is very low (not likely in this century), the effects can be that enormous (financially, socio-economically, directly in the Netherlands or indirectly affecting the Netherlands) that we are not willing to accept any risk that these events will happen.
- *International solidarity*: Although no specific research has been conducted with regard to international solidarity, stakeholders in the previous project indicated the importance of this aspect; research has indicated that risks of food and water shortage, as well as general economic impacts will be greater for developing countries, even for temperature increases below 2°C.

Risks rapidly become unacceptable for some of the sectors at relatively low increases in temperature, sometimes even close to 1°C. A warming of around 0.8°C since pre-industrial levels has already occurred. There are obvious costs for both autonomous and proactive adaptation; but these costs as well as the costs of taking mitigation action have not been covered in this report. This is because comprehensive information was not available at the sectoral level for all the impacts studied.

The previous report of the project team argued on the basis of the stakeholder discussions that the driving factors for engaging in discussions on dangerous climate change in the Netherlands are the losses to unique ecosystems such as the Wadden Sea and the coastal belt; the high economic, but also socio-political costs of coastal adaptation; the implications of the changing precipitation regime for navigation, agriculture, and infrastructure; impacts on tourism and health; irreversible and abrupt events with high associated risks; and last but not least important - the impacts on vulnerable societies and countries especially in the developing world.

During the workshop with Dutch experts organised in May 2006, the participants stated that a figure such as the burning embers figure contains much information but remains difficult to comprehend for the general public. It was necessary to make the figure more sensible and relevant for lay people. This led to a first draft of a follow-up figure. While the basis of this figure does not contain colours, a value judgment can be added by posing questions. The figure could be an online tool for the public to assess what they consider unacceptable. This could be done by framing questions in a way that people will have to value the occurrence of climate impacts ("Do I mind if climate impact X happens?") By answering these questions, it is possible to add colour to the figure, and to show people what they themselves consider 'dangerous' climate change. For impacts where there is still a lot of uncertainty, such as the large-scale abrupt events, questions could be posed in a way that explicates the uncertainty ("Do I mind that there is a probability X that climate impact Y happens?"). It is noted that such a figure or tool does not in itself address the relative importance people attach to different sectors (for example, the impacts on the coastal zone could be considered much more important than impacts on the tourism sector). The following figure contains questions composed by the research team. This is a first attempt to provide questions relevant for the project. However, many more questions can be thought of and could be included in such a figure.

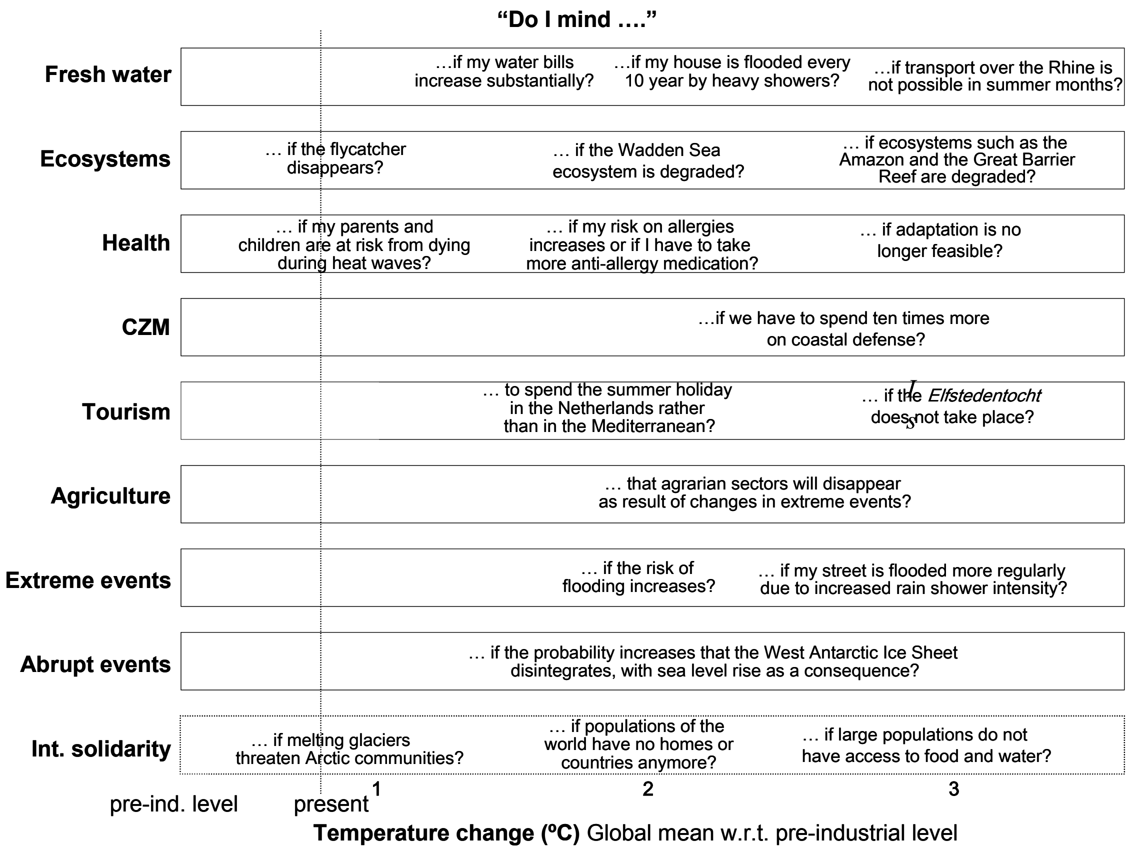

Figure 3. 'Burning Embers' figure highlighting issues of relevance for Dutch residents.

Temperature or concentration targets

Although in 1996 and 2001, the Netherlands and the EU chose to express their targets in terms of temperature increases and greenhouse gas concentrations, the realisation that the climate sensitivity might be higher than previously assumed, make many argue in favour of temperature targets as opposed to targets related to concentration levels, since the latter is a less certain parameter than global mean temperature for determining impacts. Furthermore, a long-term stabilisation of concentrations target does not take into account the inertias in the system. This means that the temperature consequences are not felt for decades to come and that a considerable warming is already committed. This means that if we wish to stabilise global temperature at 2ºC above pre-industrial levels, we need to ensure that concentrations of CO_2 equivalence are not much higher than 400 ppmv. This still does not mean that we have a 100% probability that if we stabilise at 400 ppmv that we can limit temperature rise to 2ºC above pre-industrial levels. This is because of the large number of uncertainties in the system.

Policy recommendations

This report has highlighted the observed and expected impacts of climate change on several areas of importance to the Netherlands, and has explained how these impacts can be seen as potentially dangerous in the sense of Article 2 of the Climate Change Convention. In this regard, the findings of this report are also relevant for the Adaptation Programme for Spatial Planning and Climate (*Nationaal Programma Adaptatie Ruimte en Klimaat*; ARK), which aims specifically to address the nature and magnitude of observed an expected climate impacts.
This report concludes that the impacts of climate change on the Netherlands can be classified into three categories in relation to a possible 2°C rise in global mean temperature from pre-industrial levels:

- Mainly positive effects expected: tourism and recreation and the agricultural sector may stand to gain if food production falls in other parts of the world;
- Mainly negative effects expected: for health, fresh water, and coastal zone management. For these sectors, we may have to invest heavily in adaptation in order to maintain the status quo. For species and ecosystems it is clear that there will be adverse impacts, which means that a combination of mitigation and adaptation is needed;
- Unclear: for large-scale abrupt events, there remains much uncertainty. Most scientists believe that the risk of abrupt events will increase with increasing global mean temperatures.

It can be seen that some of the impacts have an explicit international component, which can be regarded as relevant for the determination of what is dangerous for the Netherlands. These include the potential impacts of abrupt events, which would have global impacts by definition; ecosystems, which are at larger risk in other parts in the world than in the Netherlands; and the impacts on other, more vulnerable regions and countries. However, there are also some impacts that have an international component, which could imply a positive outcome for the Netherlands, such as increased tourism in the Netherlands, or shifts in agricultural production.

In general, the risks for climate change impacts increase gradually (although not always linearly) with increasing temperatures. While for the tourism sector a temperature increase of 3ºC compared to pre-industrial levels may seem acceptable; and impacts on agriculture may be limited, for the bulk of the other sectors a 1-2ºC rise in temperature implies approaching threshold limits. We believe that beyond a 2ºC global warming in relation to pre-industrial levels the probability of occurrence of low-probability high-risk events increases. Agreeing to the 2ºC target implies that ecosystems and species would be at considerable risk, and that numerous proactive adaptation activities would have to take place in the fresh water, health, coastal zone management and agricultural sectors. Furthermore, the impacts that would still occur on other vulnerable regions of the world should not be neglected. The 2°C target could imply adverse impacts on other, more vulnerable countries.

As we have already warmed around 0.8°C since pre-industrial times, this means that a stronger focus on adaptation some of the abovementioned sectors is justified. However, this is not to suggest a total shift towards adaptation policy. On the contrary, the current and expected impacts on, for example, ecosystems around the world, as well as vulnerable countries emphasise the importance of mitigation policies.

According to recent literature, to stay with considerable certainty below a 2ºC warming limit implies stabilising CO_2 equivalent concentrations at 400 ppmv. This is considerably lower than the previous concentration target of 500-550 ppmv. Further relaxing the temperature target raises the risk of putting larger number of species and ecosystems at risks of extinction and would neglect the impacts of climate change in other parts of the world. Clearly, while such a target is a political goal, committing to such a target only makes sense when other developed countries also soon engage in such commitments, followed later by all the other countries.

According to VROM (2006), the short-term climate targets for the Netherlands for 2010 will be achieved. Furthermore, it also states that it is technically feasible to avoid exceeding the 2°C target. This conclusion seems premature, given that achieving the Kyoto targets certainly does not ensure in itself that the long-term ambition of the Netherlands will be fulfilled. Furthermore, as indicated in this report, there is still much uncertainty on the stabilisation pathway that is needed to stay below 2°C. Given that we are already well on our way towards this temperature increase, and given that it is more probable that lower stabilisation levels are required than initially thought, we recommend to examine which emission and stabilisation pathways need to be followed to achieve the Netherlands' long-term political ambitions.

1 Introduction

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1.1 The problem definition

Assessing when climate change becomes dangerous for the world is a complex task. One step towards assessing when climate change becomes dangerous is to examine how countries experience and perceive the impacts of climate change. Two years ago, a team of Dutch researchers in collaboration with a number of social actors came to a preliminary assessment of when the impacts of climate change could turn dangerous for the Netherlands. Against this background, the purpose of this project is to revisit the research results in the light of new research and to improve the quality and robustness of the assessment. This chapter presents briefly some background information (see section 1.2), then summarises the results of the previous research (see 1.3), gives the objectives and research questions (see 1.4), develops a methodology (see 1.4), and finally presents the structure of this report (see 1.5).

1.2 Background

The climate change problem is being addressed through an international framework convention (the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and a series of negotiated or anticipated protocols. The Convention provides a long-term objective in Article 2:

> *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."*

In 1997, the Kyoto Protocol to the UNFCCC was adopted. The Protocol includes quantitative commitments for the developed countries and designs mechanisms to help countries achieve their commitments in a cost-effective manner. The Protocol sets an overall target of a reduction of 5.2% of global emissions by the year 2008-2012. This is very low in relation to the level of emission reductions that may be considered necessary in order to protect the earth from dangerous interference. Of course, the determinations of whether this is low or not depends on ones interpretation of what dangerous emission levels are.

The level at which the concentrations of greenhouse gases are eventually stabilised determines the overall level of global climate change. At the same time, the level of climate change and the severity of its impacts are highly uncertain, particularly at the regional level. Given the large uncertainties about the impacts of different stabilisation levels it is necessary to address the question: do we need to set long-term stabilisation targets in relation to greenhouse gas (GHG) concentrations, and are concentrations of GHGs in the atmosphere the most appropriate indicator for setting long-term targets?

Climate change negotiations have so far focused almost exclusively on short-term issues related to greenhouse gas mitigation in the first commitment period (2008-2012) and the use of flexibility mechanisms in the Kyoto Protocol. However, action outlined in the Kyoto Protocol represents only an initial step towards achieving the overall objective of the UNFCCC. During a global project on Article 2 (HOT phase 1; see Gupta et al., 2003), we discovered that most negotiators get so involved in the nitty gritty details of negotiating short-term goals on the basis of narrow national interests, that they lose sight of the long-term objective and what it implies for national commitments. It is therefore necessary to look beyond shorter-term imperatives in order to address this objective and contribute towards a sound and equitable long-term solution to the challenge of climate change.

At the same time, the debate on ratification and entry into force of the Kyoto Protocol has been marked by calls to broaden the ambit of the Protocol by including developing country GHG mitigation commitments. These demands have been countered by developing countries by references to their low cumulative and current per capita GHG emissions, low per capita incomes, low GHG intensity of GDP at purchasing power parity, and high vulnerability and poor coping capacity to climate change impacts. There is an increasing awareness amongst developing countries of the implications of climate change and demand for international climate policy making to deal not only with mitigation but also the issue of adaptation. Therefore there is a strong need for dialogue amongst policymakers and stakeholders about acceptable and unacceptable climate change impacts, about fair ways of dealing with the unequal distribution of impacts, and about options for a fair distribution of emission control and adaptation costs.

The level of climate change impacts is related to both the overall magnitude of the change, the rate at which it occurs, and the ability of the natural and human systems to tolerate or adapt to the change. Not all systems are equally vulnerable to climate change: some systems are likely to adapt more easily than others. Human systems may adapt more easily than natural systems, while developed countries generally have more adaptive capabilities than developing countries. In assessing dangerous levels of climate change, adaptation options and capabilities need to be taken into account. This raises questions about how to evaluate different types of impacts and how to deal with regional and social differences in impacts. This also raises questions about critical impacts (impacts that should guide actions) and intergenerational solidarity (i.e. what time horizon should be taken when considering climate change impact risks).

The climate change problem basically constitutes a risk problem, where climate change impact risks need to be balanced against the risk of climate control policies. Acceptable levels of climate change will be defined in relation to the possible societal consequences of impacts, adaptation, and mitigation efforts. An assessment of non-dangerous climate change thus also entails an assessment of the implications of climate change control policies and their costs.

Climate change scientists are unable to define what would be an acceptable level and time frame for global concentrations of greenhouse gases to be stabilised. This is because the evaluation of climate change risks is essentially a political issue. Moreover, scientific uncertainties make it very difficult to assess the likelihood of possible climate change events and thus to quantify the risks of climate change. In short, the climate change issue is characterised as an unstructured problem where both the values at stake as well as the science are uncertain and subject to debate.

1.3 The Re-evaluation of the Netherlands Long-Term Climate Targets project

To address the question of what dangerous climate change means for the Netherlands, the project Re-evaluation of the Netherlands Long-Term Climate Targets (NLTCT project; 2004) was initiated. More specifically, the project addressed the following substantive questions:

- How can Article 2 of the UNFCCC be elaborated into quantitative indicators for climate change control? What operational criteria could be developed to indicate dangerous and non-dangerous levels of anthropogenic interference with the climate system? What indicators can be selected that are both politically relevant and publicly comprehensible and appealing, and can be scientifically substantiated (attributable to climate change, reliable/valid, measurable, predictable)? How can different indicators be aggregated?
- What are the options for adaptation to avoid exceeding thresholds levels? What level of adaptation is feasible and acceptable?
- How can the indicator levels be related to the possible scenarios? How are the indicator levels and the risks of exceeding of critical levels related to levels of climate change? How can the levels of climate change be related to long-term goals for stabilization of greenhouse gas concentrations? How do these long-term concentration levels relate to greenhouse gas

emission levels on the long term and the short-term? What would be the implications of limiting the risks of exceeding long-term indicators thresholds levels for global emission control on the short- to medium term (the post Kyoto period)?
- What are the options and costs of meeting long-term stabilization targets? How are its feasibility and costs related to socio-economic and technological developments, social and institutional barriers, and the timing of mitigation efforts? How can risks of high future policy adjustment costs be limited (e.g. hedging)?
- How can we deal with the unequal distribution of climate impacts and mitigation capabilities? What can be the role of supporting adaptation and/or providing compensation? How can mitigation costs be (e)valuated against adaptation costs/climate impacts?
- What is the value of climate indicators and long-term climate targets for developing an effective international climate change regime and rallying societal support for dealing with climate change?

On the basis of scientific assessments and stakeholder workshops, the team identified preliminary indicators and threshold levels as shown in Table 1.1.

Table 1.1. Preliminary list of indicators and threshold levels.

Priority	Indicator	Acceptable risk	Not acceptable
A	Access to clean drinking water	That there is a temporary ban on washing cars; or watering gardens	That children cannot bathe; or you cannot drink water from the tap;
	Death from heat waves	Mortality remains stable	An increase in mortality
	Allergies and other chronic sicknesses due to longer pollen season		Structural increase in chronic sicknesses
	Rate of sea-level rise	20 cm per century	> 50 cm per century; > 3 mm per year, because of the devastating effects on the Wadden sea
B	Water quality (no. of weeks one cannot swim)	An increase of 50% from current levels;	An increase of 200%; Structural effect annually
	Navigability of rivers	Incidentally less load	Over four weeks less load Over two weeks less load
	Water temperature	An incidental rise leading to fish kills	Structural rise leading to loss of biodiversity; Code red: Electricity is rationed, because of the impact on electricity production
	Spread of infectious disease	An increase in the chance of falling ill	If adaptation is no longer possible, or if the costs for adaptation are out of proportion
	Floods	Incidental increases	Structural increases affecting property values
C	Productivity of land	Incidental losses	Structural losses
	Absolute seal level rise	Marginal increases	> 0.5 m too costly
	Effect on work and sectors	Marginal changes	Income inequality increases
	Disappearance of species	Incidental losses	Where the legal norms are exceeded and structural losses
	The number of major skating events (Elfsteden tochten)	Less than current levels	Less than once every ten years
D	Effect on income	Incidental loss of income	No growth as result of impacts for one year; If Netherlands competitiveness is affected
	Change in biodiversity	Incidental changes	Loss of key species and ecosystem functions
	Melting of glaciers	Incidental changes	Structural large-scale
E	Impact on the Gulf Stream	Negligible chance	Increase of probability
	Rate at which the beach disappears	When the beach can be easily replenished	When replenishment is too expensive affecting tourism
	Instability through North-South impacts	At current levels	Should not increase structurally
F	Disintegration of the Antarctic	Negligible chance	Increase of probability
	Global access to drinking water	Should meet Millennium Development Goals	Should not become worse than today
	Storms	Current levels	Should not increase structurally
G	Access to food	Current problems	When this leads to international instability and significant increase in financial inequality

Source: Gupta & van Asselt (eds.), 2004.

In addition, a communicative figure (Figure 1.1), depicting for different sectors for which temperature rise there is a perceived reason for concern about climate change impacts, was developed.

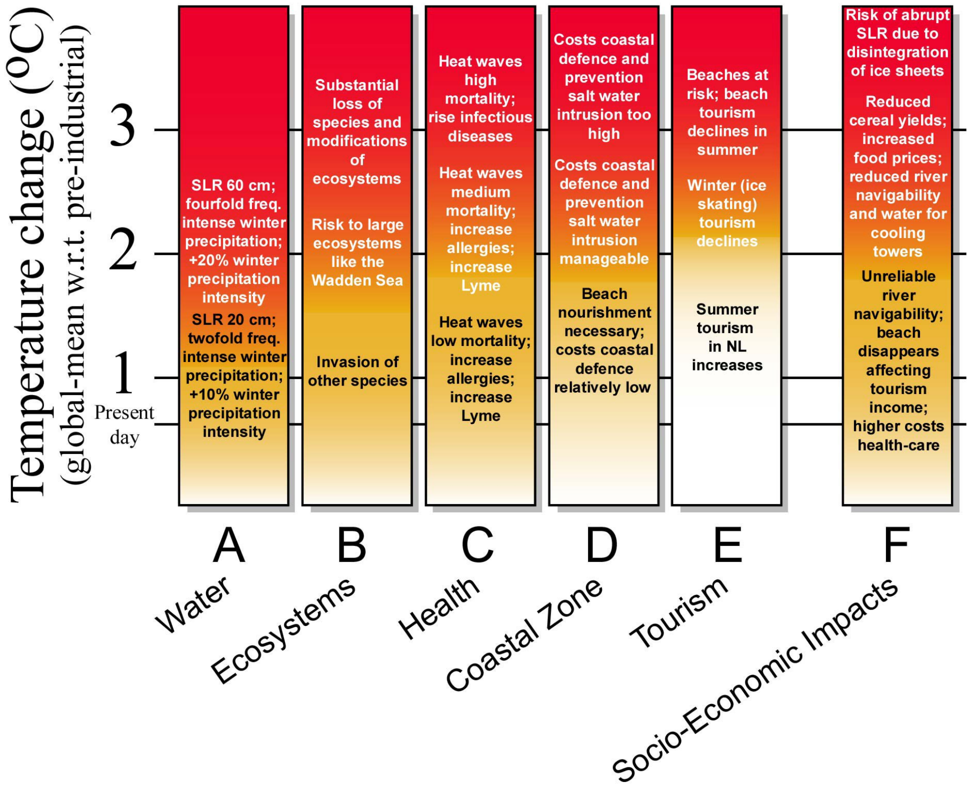

Figure 1.1. Perceived levels of danger associated with different levels of temperature rise (Gupta & van Asselt (eds.), 2004).

The key strength of the NLTCT project was that it forced the researchers and stakeholders to think about the specific impacts of climate change on the Netherlands and what would be perceived as unacceptable threshold levels. The weakness was that we were unable to find a method in the time available to reflect on the depth, gaps and quality of the scientific information underlying the assessment. We also experimented with a methodology that needs to be made more robust and reproducible, as well as placed in the context of other such methods for defining dangerous climate change. The present report attempts at dealing with these weaknesses and focusing precisely on improving the methods and the scientific results.

1.4 Objectives and research questions

The **objectives** of this project are:

- Conduct a scientific assessment of existing methods of articulating dangerous climate change in the field;
- Assess the latest literature on dangerous climate change and climate impacts in general and update the indicators and threshold levels developed in the NLTCT project on the basis of the latest scientific assessment;
- Assess the availability and gaps in scientific knowledge, as well as its quality (uncertainty) in assessing dangerous climate change for the Netherlands;
- Thereby both contributing to the way the Netherlands prepares for the international negotiations on the issue; and to the anticipated global and national dialogues on Article 2.

The specific **research questions** for this project are:

- What are the different research methods to identify dangerous climate change, and what are the major uncertainties and disagreements between approaches?
- What are the implications of the newest assessments of climate change science, economics, politics and law for the articulation of indicators of climate change and dangerous thresholds for the Netherlands?

- What are the gaps and availability in knowledge and the quality of the scientific information with regard to the indicators and thresholds in for assessing dangerous climate change in the Netherlands?
- How can the availability (and gaps in knowledge) and quality (uncertainty) of existing scientific information on impacts be taken into account in communicating this to stakeholders?

1.5 Methodology

The methodology developed for this project was influenced by the literature survey (see Chapter 2) and the experiences of the project partners involved. Based on an initial discussion and a workshop between the project partners, a systematic methodology was developed. It involved the following six steps.

1.5.1 Identification of the sectors

The first step was examining whether the sector covered in the previous project were comprehensive and reflected the impacts in the Netherlands. The previous research process lead to the identification of the following sectors: water, ecosystems, health, tourism, coastal zone and socio-economic sectors. For this report the team decided to include:
- Certain impacts on the industrial sector (because there are clearly strong impacts on the industrial sector, and some indicators selected by the stakeholders in the NLTCT project can be more easily linked to the industrial sector).
- Agriculture (because this is clearly an important sector for the Netherlands, even though it is unclear at present whether this sector, including the trade impacts, will be affected by climate change. It was decided to exclude forestry and fisheries from this category for the time being).
- Abrupt events (because this is clearly important in its own right).
- International issues (because the stakeholders had indicated that some international indicators were of interest to the Dutch people, partly out of solidarity, and because they might also concern security issues).

The team decided to no longer include a broad category of socio-economic impacts, but to try and examine such impacts within the context of the sectoral evaluation.

1.5.2 The identification of indicators per sector

The second step was to identify the indicators per sector. In general, the team decided for aesthetic and feasibility reasons to select three indicators per sector. The criteria for revising and selecting indicators include:
- Whether the stakeholders in the NLTCT project had selected these;
- Whether the indicators used by other studies in other parts of the world (based on the literature review in Chapter 2);
- The availability of information per indicator;
- The degree to which such indicators had a likelihood of appealing to stakeholders in the Netherlands, based on whether the project team could justify the selection to its peers; and
- The severity of the impacts on the sector.

In the initial discussions, the indicators per sector were selected as indicated by Table 1.2. The team decided not to include a general section on impacts on the economy as there was limited research on the subject with respect to the impacts on work and impact on income on a more aggregate level, and because these impacts were partly covered by the discussion of sectoral indicators. For ecosystems, the focus shifted to categories – plants and trees, mammals, birds and marine species. For tourism, two indicators (i.e. water quality or the number of weeks one cannot swim; and the rate at which the beach disappears) were ultimately not researched.

Table 1.2. Indicators selected for this report.

Sector	Indicators used
Fresh water	River discharge: design discharge River discharge: low flow Precipitation: 10-day precipitation sum Precipitation: precipitation deficit
Ecosystems	Disappearance of species Red list species Change in biodiversity
Health	Heat wave mortality Pollen allergies Lyme disease
Coastal zone	Coastal squeeze Safety against flooding Salt-water intrusion
Tourism	Suitability of Dutch climate for recreation and tourism The length of the outdoor recreation and tourism season The frequency of *Elfstedentochten*
Agriculture	Crop productivity Damage from extreme events Commodity prices

For abrupt events, particular attention was paid to:
- Disintegration of the West Antarctic Ice Sheet;
- Disintegration of the Greenland Ice Sheet;
- Slowdown/collapse of the thermohaline circulation.

Since the Netherlands is part of a global community of nations, and since the stakeholders had suggested a number of international indicators, the project team decided to include various international issues. This includes examining:
- People at risk from limited access to water and food;
- Loss of iconic species, systems (e.g. glaciers) and cultures (e.g. in the Arctic and in small island states);
- North-South instability.

1.5.3 The identification of threshold levels per indicator per sector

The project team decided to revisit the original threshold levels using the following criteria:
- start from the previously selected thresholds;
- verify which part is scientific and which part is a value judgement;
- use thresholds that are incorporated in the policy and legal documents;
- check if there are strong reasons to change the thresholds;
- check if there is a major difference of opinion and how that should be reflected;
- draw up a list of limitations associated with the choice of threshold level.

1.5.4 Version of the 'Burning Embers' figure for the Netherlands

The project team decided to make a version of the 'Burning Embers' figure for the Netherlands, which would include adaptive capacity and thereby show vulnerability of the Netherlands.
In dealing with adaptation, each sector would cover the following elements:
- General elements such as technological, financial, scientific and institutional expertise; and
- Sector specific autonomous adaptation and non-autonomous adaptation (which would include easy options and a discussion of more difficult options because of the problem of technological and institutional lock-in).

- In order to enhance the scientific quality of the colour code used, the project team decided that the code would go from white to red, with white implying 'non-significant risk' and red meaning (exceeding) unacceptable thresholds of risk.

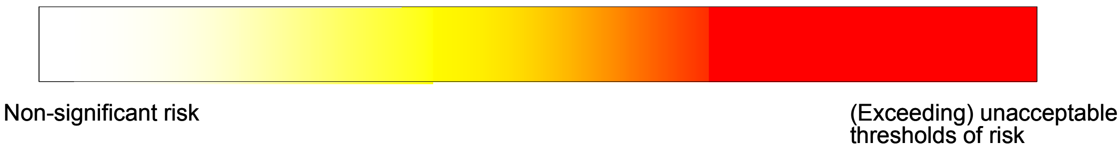

Figure 1.2. Legend for 'Burning Embers' figure.

It also decided to include a text box in the figure to help the reader interpret the risk and its relationship with danger.

1.5.5 Scientific robustness

Given the cascading set of uncertainties in the research, the project team decided to be very explicit about the limitations of the research; and to expressly indicate the quality of the research, the gaps in research and what needs to be further investigated. Since the information available on the impacts is not evenly distributed, the project team decided to use the following codes to show how robust the science is:

+++ well established: multiple articles using different methods; one article can be good enough if it is robust and based on a lot of information; team uses expert judgement.
++ anecdotal: a few scattered articles.
+ speculative/intuitive: not enough information available but it is possible to speculate on the basis of general information that is available.

1.6 The structure of this report

This report is structured as follows. We first undertake a detailed literature analysis of the methods and results of analysing how dangerous climate change should be defined. This assessment is provided in Chapter 2. Chapter 3 looks at the latest data with respect to the climate science and the impacts on the Netherlands. Chapters 4-9 provide sectoral assessments of the potential impacts of climate change in the Netherlands or of relevance to the Netherlands. Finally, Chapter 10 integrates the research into a comprehensive table and revised 'burning embers' figure for the Netherlands.

2 Defining Dangerous Climate Change: A Bird's Eye View of the Literature[2]

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2.1 Introduction

The current concentration of CO_2 (380 ppm) is higher by about 100 ppm than it has been over the last 730,000 years. This is happening at 10-100 times the rate that has occurred over the last 420,000 years (Steffen et al., 2006). As far back as 1990, international declarations adopted a working definition of the end goal for the climate change regime, which was at that time still under development. At Toronto in 1988, 300 scientists and policymakers from 46 countries met to discuss the issue and concluded that "[h]umanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war" (Toronto Declaration, 1988). In a 1988 speech, Margaret Thatcher stated that "[i]t is possible that (…) [w]e have unwittingly begun a massive experiment with the system of the planet itself" (cited in Carvalho & Burgess, 2005: 1462). The 1989 Noordwijk Declaration on climate change stated:

> *"For the long term safeguarding of our planet and maintaining its ecological balance, joint effort and action should aim at limiting or reducing emissions and increasing sinks for greenhouse gases to a level consistent with the natural capacity of the planet. Such a level should be reached within a time frame to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and permit economic activity to develop in a sustainable and environmentally sound manner. Stabilizing the atmospheric concentrations for greenhouse gases is an imperative goal" (Noordwijk Declaration, 1989: para 8).*

These initial declarations provided the political motivation to define an end goal for the United Nations Framework Convention on Climate Change (UNFCCC). The first report of the Intergovernmental Panel on Climate Change (IPCC) provided an 'if… then' definition which was worded as follows: "[i]f there are critical concentration levels that should not be exceeded, then the earlier emission reductions are made the more effective they are". This statement was followed by a table which illustrated that if concentrations were to be stabilised at 1990 levels, there would be deep cuts required in emission levels (Houghton et al., 1990: xvii-xviii).
These declarations eventually inspired the formulation of Article 2, the ultimate objective of the UNFCCC,[3] which reads:

> *"The ultimate objective of this Convention (…) is to achieve (…) the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."*

This begs a number of questions: what is 'dangerous anthropogenic interference'; when do we consider climate change dangerous; and to whom does climate change pose a danger (Pachauri, 2006; Yamin et al., 2006)? Although Article 2 provides some guidelines on this with regard to ecosystems, food security and economic development, there is no precise greenhouse gas concentration level indicated. Despite this fact, it provided sufficient guidance – through the concept of a 'safe corridor' (Oppenheimer & Petsonk, 2005) – for the first stage of the negotiations leading up to the emission reduction targets contained in the Kyoto Protocol. In fact, it is argued that the vagueness of Article 2 is intentional, and that it provided the basis for discussing more short-term measures (Yamin et al., 2006). The low level of the Kyoto targets,

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[2] Parts of this chapter have been accepted by Review of European Community and International Environmental Law and parts will be submitted to another journal.
[3] For a more elaborate historical account, see Oppenheimer & Petsonk (2005).

however, motivated many to discuss the insignificance of the targets set out in the Kyoto Protocol. Some used these targets to argue that it did not make sense to go down the Kyoto road,[4] whereas others to argue that precisely because of the political negotiating process, it was urgent to rapidly consider at what level climate change could become dangerous and then to determine what levels of emission reductions needed to achieved by when.

Although the vagueness of Article 2 did not prevent countries to agree on the Kyoto targets, a discussion of the UNFCCC's ultimate objective has not taken place in the negotiations after its adoption (Oppenheimer & Petsonk, 2005). In the scientific literature, however, there has been a recent surge in research that deals more thoroughly with the challenge of defining dangerous climate change. We have assessed a range of the literature that have examined dangerous climate change. The purpose of this chapter is to analyse the existing literature to understand: (a) how dangerous climate change is being defined; and (b) which methodologies are used to articulate dangerous climate change. We note that 'dangerous anthropogenic interference with the climate system' is not the same as 'dangerous climate change' (Lorenzoni et al., 2005: 1387);[5] however, we will use these terms interchangeably throughout this chapter.

This chapter is structured as follow. Section 2 discusses the rationale for defining dangerous and setting long-term targets, and provides a brief overview of the different possibilities for setting long-term climate targets. Section 3 then explains the different schools of thought on the role of science in determining what is dangerous. Section 4 then provides an overview of the different methods used in the literature to help operationalize Article 2. Section 5 addresses some unresolved issues in the literature, including the role of adaptation. Finally, Section 6 provides some conclusions.

2.2 Long-term targets: rationale and types

2.2.1 Rationale

A destination is important for any project undertaken by humans. Where one wants to get to, helps one design strategy and the tactics to arrive there (Gupta & van Asselt, 2006). The use of well-established means per se does not guarantee that one will reach the end goal aimed at. This in brief is the crux of the problem: why define dangerous climate change? Retallack (2005) provides a number of arguments of why one should define dangerous climate change by setting a long-term objective. These include:

- the need to inform business communities, in order for them to make investment decisions that span several decades;
- the need to communicate the scale of the problem to the public;
- the need to prevent the foreclosing of future climate policy options, which would imply certain climate impacts, also related to the inertia in the climate system; and
- the need to provide a 'destination' that informs current negotiations for the next commitment period of the Kyoto Protocol.

Further arguments include increasing the awareness of the long-term consequences of current GHG emissions; measuring progress; mobilizing society; and broadening participation of countries in the climate regime (Pershing & Tudela, 2003; see also Corfee-Morlot & Höhne,

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4 As Oppenheimer and Petsonk (2005: 202) correctly point out, this argument ignores the fact that it is well-known that the Kyoto Protocol is but a first step towards further emissions reductions, which are needed for stabilisation of greenhouse gas concentrations.

5 This is related to the question to what extent climate change is caused and will continue because of anthropogenic or natural factors. Many sceptics have argued that human contributions to greenhouse gas emissions are so low (about 4%) that it is arrogant of humanity to think that this could lead to substantial destabilisation of the climate system (e.g. Priem, 1995; Boehmer-Christiansen, 1996). On the other hand, others argue that it is this very 4% that is critical. As the IPCC (Houghton et al., 2001: 10) put it: "[t]here is new and stronger evidence that most of the warming observed over the last fifty years is attributable to human activities".

2003).[6] This chapter takes the basic starting point that if we need to determine appropriate timetables for emission reductions, then we need to have a methodology to determine when climate change becomes dangerous (cf. Mastrandrea & Schneider, 2006).
It can be seen that the literature on dangerous climate change tends to either consist of a search for a single target that would indicate when climate change becomes dangerous (most of the authors referred to in this chapter) or to promote the idea that defining dangerous is a continuous process of social engagement with scientists to understand how the problem can be addressed (Patwardhan & Sharma, 2006; Yamin et al., 2006). Critics will most likely argue that it is an impossible task to reach international agreement on what is dangerous.[7] However, it is important to keep in mind that even if no long-term targets are agreed upon, the process itself can be a valuable exercise.

2.2.2 Types of long-term targets

Between those authors that aim to come up with a single target, there are important differences in how this target may be expressed, each with their own pros and cons (Pershing & Tudela, 2003). These types of targets can be related to various stages of the climate change cycle, ranging from the human activities to the climate impacts to be avoided. Table 2.1 summarizes the pros and cons of these approaches.

Oppenheimer and Petsonk (2005) argue that a concentration target is most appropriate as a regulatory tool, because of its status in Article 2; it is less variable than mean temperature, and since concentrations lead climate change, while temperature lags concentrations. There is an important difference in setting the concentration targets for merely carbon dioxide (CO_2), or also for other GHGs (CO_2-eq.). Baer and Athanasiou (2004) argue that policy-makers and scientists have not always treated this distinction carefully. Furthermore, they point out that oftentimes there have been inconsistencies if more than one target has been explicated (e.g. when not only a temperature, but also a concentration target is given).

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6 Pershing and Tudela (2003) also note some of the arguments against setting a long-term climate target, including: the difficulty to come to an agreement; drawing away attention from short-term action; the setting of a target that is too weak; and the risk of a backlash if too stringent a target is set.

7 Nevertheless, Yamin et al. (2006: 88) state that “[i]t is certainly within the realm of possibility then that a consensus can be achieved on a dangerous level of climate change, particularly if that level is defined at a relatively low level to ensure that all possible dangers have been taken into account”.

Table 2.1. Ways of expressing long-term (LT) targets along the climate change cycle

Type of LT target	**Pros**	**Cons**
Impacts to be avoided	Avoiding damages is the ultimate rationale	Requires understanding of the likely magnitude, timing, and distribution of climate impacts, and adaptation options
	Costs of impacts can be weighed against costs of mitigation	Can only drive action if reflected in earlier stages of climate change cycle
	Local nature provides rationale for action	Local nature complicates negotiations at global scale
Temperature	Avoids uncertainties on relation between temperature change and specific impacts	Temperature changes differently in different regions
	Temperature and related SLR are the main climate change effects	Uncertainties with regard to timing remain
	Effects are global and shared by all countries and individuals	Uncertainties in relation between temperature change and concentration level
	Useful as a proxy	
	Understandable indicator	
	Temperatures are routinely and accurately monitored	
Concentration	Increased GHG concentrations are the most direct cause of climate change	Uncertainties to relate concentrations to temperature and impacts increase[8]
	Concentrations are routinely and very accurately monitored	Not clear how to relate concentration to mitigation efforts
	Concentrations reflect the cumulative total of all global activities	
	Article 2 refers to concentrations	
Emission reductions	GHG emissions are seen as cause of climate change	Another layer of uncertainty between chosen metric and avoided impacts
	GHG emissions are frequently related to other air pollutants to be reduced for public health reasons	Could result in a cost-benefit analysis with large costs and unclear benefits
	Each country has authority to control domestic GHG emissions	
	Emissions are well-monitored	
Human activities	Human activities are ultimate cause of climate change	Furthest away from impacts; no assurance that ultimate goal will be achieved
	Possible side-benefits (e.g. air pollution)	All uncertainties mentioned above are present
	A technological goal may gain political support	Risk of technology lock-in
	Best point to directly affect cycle	May be less cost-effective

Based on Pershing & Tudela (2003).

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8 Allen et al. (2006: 288) argue: “it is essential that the ultimate policy target remains defined in terms of temperature change to be avoided, and that we ensure this is not replaced by a ‘dangerous greenhouse gas concentration’, which is impossible to define objectively”. Their main point is that concentrations should be adjusted with increasing knowledge about climate sensitivity.

2.3 The role of science

The literature reveals three schools of thought on whether and/or how science can contribute to a definition of 'dangerous climate change'. Some argue that defining dangerous is purely a political question and that science is not in a position to be able to make any serious and sound comments about the issue. Victor (forthcoming), for example, submits:

> *"For the same reasons, efforts to build an international regime to control climate change on a shared 'objective' are likely to fail because countries in fact do not have shared assessments of the danger and opportunity. Article 2 of the UNFCCC lays out exactly that objective (…). Those efforts are built on an unrealistic vision of politics. It is perhaps understandable that diplomats, whose job description includes the manufacture of a seemingly logical order to what is in a fact a highly political process of sausage making, would create something like Article 2; why sober analysts would devote so much attention to the impossible task of actually measuring the true meaning of Article 2 is mystifying."*

In a similar vein, but using a different argument, Barrett (forthcoming) states:

> *"A related problem is defining 'dangerous interference'. To my knowledge, there is no evidence that climate change poses a threat to civilization. Indeed, if it did, and we knew the level of concentrations that would destroy civilization, we could pretty much count on the world to avoid this danger. Ironically, climate change is a collective action challenge partly because its effects on the aggregate of humanity are expected to be limited."*

Also Tol and Yohe (2006) are not convinced that defining dangerous is possible:

> *"any attempt to define scientifically what constitutes 'dangerous interference with the climate system' is bound to fail: The needed value judgements have no role in science, and values cannot be objectively aggregated."*

This school of thought seems to provide an argument for some governments for inaction, as they argue that there is not enough scientific insight as to what constitutes 'dangerous' (Dessai et al., 2004).

A second school of thought argues that science can make at least a partial contribution to understanding whether climate change can be seen as dangerous (see, for example, Steffen et al., 2006; Mastrandrea & Schneider, 2006). It is argued that significant impacts can be forecasted on the basis of both models and experienced weather changes in the last decade, and that the information on climate change impacts can help policymakers to interpret Article 2 (Corfee-Morlot & Höhne, 2003; Corfee-Morlot et al., 2005; Oppenheimer & Petsonk, 2005). As Pachauri (2006: 3) puts it, "[w]hat is dangerous is essentially a matter of what society decides. It is not something that science alone can decide. But, science certainly can provide the inputs for facilitating that decision". Or, as Schneider and Lane (2006: 7) indicate, "determination of 'acceptable' levels of impacts or what constitutes 'danger' are deeply normative decisions, involving value judgements that must be made by decision-makers, though scientists and policy analysts have a major role in providing analysis and context".

A third school of thought submits that where problems are urgent, the science uncertain, the stakes high, post-normal science is necessary (Funtowicz & Ravetz, 1993). This calls for discussions with social actors within society to determine what is an acceptable risk level and then to push for political decision-making within society (Dessai et al., 2004; Gupta & van Asselt (eds.), 2004; Gupta & van Asselt, 2006; Lorenzoni et al., 2005). This is also very much in line with the precautionary principle; where we cannot wait for full scientific certainty, but we have to take action to prevent potentially irreversible consequences (e.g. Rio Declaration, 1992; UNFCCC, 1992; see also Kovats et al., 2005; Oppenheimer, 2005). There are two major differences in perspective between the third and the first schools of thought. The first is the focus on the precautionary principle; hence, the reliance on natural science to establish facts and causal relationships is considered less important than the ability to take decisions under uncertainty. The second is that rather than seeing human civilization as some abstract concept, the real impacts on people, ecosystems and countries are seen as important, and the need to take responsibility for climate change impacts is seen as justified. In other words, more emphasis is put here on the 'value judgment' part of defining dangerous. It is acknowledged that making these value judgments is subjective; however, making such value judgments can be informed by ethical, legal or moral arguments (cf. Ott et al., 2004). Hence, social sciences can play an important role in this regard for defining dangerous. Nevertheless, it should be acknowledged that there is a fine line between the second and third schools of thought, which both advocate at a role for science.

Having explained the three schools of thought, this chapter devotes itself further to understanding how those who see the need to define dangerous climate change are actually dealing with different aspects of the issue. In other words, this chapter examines papers written by the 'sober analysts' that are concerned with giving Article 2 an operational definition. It is clear that most articles submit that science and scientific papers fall short of providing proof that climate change is dangerous because of the 'cascading pyramid of uncertainties' (Schneider, 1983; 2002; Schneider & Lane, 2006) or 'explosion of uncertainty' (Jones, 2000) in the science, and because of the inherent values involved in making choices. This is because (a) there are so many uncertainties in the causal chain from emissions to impacts;[9] and (b) ultimately 'how much is too much' is a matter of value judgment. As Oppenheimer (2005) explains, there are limits to what natural science research can offer in terms of objective definitions of dangerous climate change. Even an examination of only geophysical impacts reveals that it is not possible to provide objective and certain information about what is dangerous.[10] And while there is relatively a large amount of work undertaken to understand the geophysical issues, there is much less undertaken to understand the impacts of climate change for societies worldwide. For example, in the area of health impacts, relatively little work has been done. For this particular area of research, Kovats et al. (2005) recommend that a methodologically sound health study should analyse empirical historical data to draw conclusions about the future (see also Chapter **6**).[11] However, even when there is less uncertainty about these impacts, and even when the timescales are not as lengthy as for geophysical impacts, the overall impact of these other categories is generally regarded as lower, and the impacts themselves may be local rather than global (Oppenheimer, 2005). These kinds of impacts therefore raise other questions, related to the distribution of impacts. Hence, for all types of impacts, policymakers will need to make value judgments.

Nevertheless, there can be a role for scientists in assessing risks. A standard definition of risk is probability *x* consequences.[12] Schneider (2001; 2002) argues that it is for this reason that in assessing dangerous impacts, scientists need to provide estimates of the probability of certain impacts happening, even though such estimates may be highly subjective. Other ways in which science can contribute to decision-making on dangerous climate change is through identifying thresholds and possible surprise events; and estimates about how long it may take to resolve uncertainties (Schneider & Lane, 2006).

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9 These uncertainties themselves, which can be related to for example the scope, magnitude, persistence or timing of impacts, already lead to many possible interpretations of 'dangerous' (Oppenheimer, 2005).

10 In fact, as Oppenheimer (2005) argues, the choice of categories is already a value-laden exercise, which reveals the bias of scientists.

11 Interestingly, in the same Special Issue, Poumadère et al. (2005) analyse the health impacts of the 2003 heat waves in France. They show that 14,947 premature deaths could be attributed to heat stress; although there were contextual contributing factors (Poumadère et al., 2005). The authors stress that while the health impacts in developing countries are likely to be more varied, in the Western world the key health impact is likely to be heat stress on the basis of past experience in most of the developed world.

12 Tol and Yohe (2006), in a variation to this formula explain that danger can be seen as probability *x* harm, where harm can be seen as a function of impacts and values.

2.4 Methods for defining dangerous climate change

2.4.1 Introduction

There is no established methodology on determining what is dangerous climate change. Few studies have attempted to address the question how dangerous climate change can be defined at the global level. There are very few authors that attempt to examine in a holistic manner when climate change becomes dangerous. Most address one part of the entire chain from emissions to impacts. Some have developed a top-down approach looking at scenarios, emissions, concentrations, and impacts (e.g. Schneider & Lane, 2006). Others have taken a bottom-up approach examining impacts, thresholds, temperature, concentrations, and emission levels (e.g. Corfee-Morlot & Höhne, 2003; Gupta & van Asselt (eds.), 2004; Parry et al., 1996; Swart & Vellinga, 1994).

2.4.2 A disciplinary overview

Before providing a bird's eye view of the different methods it may be appropriate to point out that different disciplines would probably focus on different aspects and approaches of defining dangerous climate change. The legal focus may be on 'substantial harm' caused to other countries; with a focus on determining when such harm becomes dangerous and, hence, the liability for such harm if a causal relationship can be proved to the satisfaction of the legal standards that are appropriate. The economist's approach may be to focus on the costs and benefits of taking measures to address climate change where the threat posed by climate change is one of the factors that taken into account. The multidisciplinary approach of studying risk focuses on accepting that a certain amount of risk is unavoidable in modern society and hence the focus is on assessing the nature and significance of the risk and then determining what level of risk a society is willing to live with. The climatologist approach could be to determine when e.g. only very slowly reversible effects set in or when relatively abrupt (over a period of 10-20 years) climate change may occur. The ethics approach could examine different ethical theories (utilitarianism, Aristotelianism, etc.) and examine whether these theories lead to similar conclusions (Ott et al., 2004). Of course, the above is merely a stereotype of the approaches, and there is much more complexity and nuance that each discipline can provide. What becomes apparent from this overview, however, is that defining dangerous is essentially a task that cannot be taken up by one single discipline, and requires interdisciplinary cooperation.

Table 2.2. An ideal-typical assessment of how disciplines would deal with 'danger'

Discipline	**Focus**	**Explanation**
Economics	Cost-benefit analysis	Such an analysis would reveal that the problem is dangerous if the costs exceeded the benefits to society.
Law	Liability; standards	Such an analysis would look at the causal chain; whether responsibility could *de facto* or *de jure* be ascribed to a legal entity; and whether current and future impacts were actionable. Standards could be used to determine what level of risk is acceptable to a society.
Ecology	Loss of biodiversity	Such an analysis would examine at what levels, populations, species, ecosystems and multiple ecosystems would be threatened.
International relations (neo-realist)	Power politics	Only if dangerous impacts are to be experienced by those in power, is action likely to be taken and then only to protect those in power.
Ethics	Ethical convergence	Such an analysis would look at the ethical concepts inherently related to 'danger' or 'risk. If all ethical theories come to the same judgment, there is a reason to adopt this judgment.

2.4.3 Classifications of impacts

Defining dangerous climate change calls for identifying indicators (Gupta & van Asselt (eds.), 2004). An indicator is information – usually quantitative – pointing to a matter (state or development) of some significance (Spreng & Wils, 2000: 4). The goal of climate indicators in general is to support the development and evaluation of climate policies. The literature points to a number of different types of indicators for what may constitute dangerous climate change, related to the type of climate change impact. Hence, the indicators could assist in identifying at what level certain climate change impacts could become 'dangerous'.

The literature on dangerous climate change has classified climate change impacts in many different ways, including the following:

- *Substantive categories*: Impacts can be either geophysical (large-scale changes impacts on society and nature), biophysical (ecosystems), or related to human health and wellbeing (Yamin et al., 2006);[13]
- *Sectoral categories*: Impacts can be classified on a sectoral basis, e.g. health; water; tourism; coastal zone etc. (Gupta & van Asselt (eds.), 2004);
- *Scale*: Impacts can be classified on the basis of the scale at which the impacts are felt from global, through regional, national to local (Oppenheimer & Petsonk, 2005; Yamin et al., 2006);
- *Country*: Impacts may be specific to certain countries (e.g. the *Elfstedentocht* in the Netherlands);
- *Absolute level and rate of change*: For some impacts (such as sea-level rise), not only the absolute level of change matters, but also the rate at which this change occurs (Oppenheimer & Petsonk, 2005);
- *Abrupt and linear*: Impacts can be classified as those that are abrupt and those that are linear;[14]
- *Reversible and irreversible*: Some climate change impacts have irreversible consequences (e.g. loss of unique species), while some impacts can be reversed (e.g. temporary loss of income);
- *Reasons for concern*: Some use reasons for concern to choose which elements to isolate for discussion (Smith et al., 2001; Gupta & van Asselt (eds.), 2004; Leemans & Eickhout, 2004);
- *Adaptation potential*: For some climate impacts, the potential of natural or socio-economic systems is higher than others;
- *Timing*: Impacts may be occurring already; other impacts may occur in the near future; whereas other impacts may only occur over a few centuries or even more.

These categories are not always mutually exclusive. Geophysical impacts are likely to cause subsequent impacts on biophysical and human systems; impacts on water resources may have subsequent impacts on for example agriculture; and impacts on a local scale may have repercussions at a global scale.

However, just identifying impacts and units is not enough. We need to know if the different indicators are comparable; i.e. how does one give weights to these different indicators; how big must the impact be, before it is significant, "how do multiple but modest deficits count versus a single extreme one" and how does one account for contextual issues (Oppenheimer, 2005: 1400).

The hypotheses that emerge from the above is that:

- An impact is more likely to be dangerous when it is abrupt and/or irreversible. By definition, it is difficult for countries to respond to and plan for abrupt changes (Mastrandrea & Schneider, 2001: 444); and
- An impact is more likely to be dangerous when the sensitivity of the system is high and the resilience of the people is low.
- The former would lead to the definition of systemic limits, while the latter may call for normative or legal limits. Hence, Beckett (2005) argues that the issue of defining dangerous

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[13] Compare with Warren (2006), who distinguishes between impacts on the Earth system, human systems and ecosystems.

[14] Although it is pointed out that some impacts may be gradual and non-linear at the same time.

is close to defining environmental standards and critical loads (see also Corfee-Morlot et al., 2005). Yamin et al. (2006), however, argue that although standards in law are levels that a society deems worthy of protection, they are difficult to apply in climate change because a) they are not able to sufficiently deal with the problem of adaptation; b) they work well where the problem is simple; and c) they reflect values, and international values are difficult to determine

2.5 Overview of indicators

The literature yields a range of different types of indicators, both explicitly named as such and implicitly through analyzing the impacts of climate change on these. Table 2.3 attempts to classify a part of the information from the literature. It should be noted that this overview is far from being exhaustive. We have looked primarily at the literature that relates climate change impacts to an interpretation of 'dangerous'. Many more climate change impact studies have been conducted, and it is outside the scope of this chapter to review and list all of these.[15] The most important impacts studies can be found in the literature referred to here.

Table 2.3 shows a certain degree of convergence in identifying important indicators of climate change, and their various features.

2.5.1 Classification by country/region

The question 'to whom is climate change dangerous' is in part addressed by studies looking at impacts at specific regions or countries (so-called 'bottom-up' studies; e.g. Gupta & van Asselt (eds.), 2004). The advantage of these types of studies could be that they provide a solid information base on regional climate impacts, and how these impacts are perceived. However, given that any thresholds resulting from such studies are highly context-specific, it may be difficult to utilize the results in international negotiations (Corfee-Morlot et al., 2005).
Thus far there have been few country/region studies to understand at what levels climate change can become dangerous for these countries or regions.[16] An Australian perspective (Steffen et al., 2006) highlights the following impacts as critical to Australia – impacts on human health (heat-related deaths), agriculture (droughts), water availability, coral reefs, and biodiversity (vulnerable ecosystems). However, the authors do not ultimately come up with a prescription of what they think is dangerous climate change.[17]

Hayhoe et al. (2006) focus on California, and examine health impacts, impacts on water, agricultural productivity and impacts of fires, and impacts from El Niño events. They provide a number of factors that could contribute to increased policy relevance of regional impact studies in determining what is dangerous. These factors are scientific (e.g. related to the use of climate models or socio-economic projections), methodological (use of a multidisciplinary team with regional expertise), resources (both physical and intellectual), and communication-related (interaction with policymakers).

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15 For an impressive overview of at what temperature levels certain climate impacts may occur on the earth system, human systems and ecosystems, see Warren (2006). In addition, see Hare (2006) for a review of the impact literature. From their studies, many more indicators can be gathered.
16 Note that this is different from studies that solely examine the climate impacts for a country/region.
17 Although they (Steffen et al., 2006: 225) indicate that 1) any significant change towards more El Niño-like conditions in Australia in the future would almost surely be seen as dangerous; and 2) the setting in of a runaway greenhouse effect would constitute the "ultimate definition of dangerous climate change".

Table 2.3. A taxonomy of indicators for dangerous climate change.

Type	Indicator	Sector/Arena	Scale	Used by
Geo-physical	Shifts in ENSO		Global, local	Steffen et al., 2006
	Rate of sea level rise	Water/ CZM	Global, local	Nicholls & Lowe, 2006
	Absolute sea-level rise	Water/CZM	Global	Lowe et al., 2006; Nicholls & Lowe, 2006
	Disintegration of the West-Antarctic Ice Sheet	Water/ CZM	Local with global impacts	O'Neill & Oppenheimer, 2002; Vaughan & Spouge, 2002; Gupta & van Asselt (eds.), 2004; Keller et al., 2005; Oppenheimer & Alley 2004; 2005; Rapley, 2006
	Impacts on Greenland ice system	Water/CZM	Local with global impacts	Folkestad et al., 2006; Hassol & Corell, 2006; Lowe et al., 2006; Schneider & Lane, 2006
	Slowdown/Shutting down of the thermohaline circulation	Water/CZM	Regional, with global impacts	O'Neill & Oppenheimer, 2002; Gupta & van Asselt (eds.), 2004; Challenor et al., 2006; Schlesinger et al., 2006; Wood et al., 2006
	Changes in monsoon	Water/ agriculture	Local, regional	Brooks et al., 2005; Steffen et al., 2006
	Ocean acidification	Fisheries/ ecosystems	Global	Turley et al., 2006
	Acceleration of global warming through ecosystems ('runaway greenhouse effect')	Ecosystems	Global	Brooks et al., 2005; Cox et al., 2006; Steffen et al., 2006
Biophysical	Disappearance of species	Ecosystems	Local	Hare, 2006; Steffen et al., 2006
	Destruction of ecosystems	Ecosystems	Local to regional	Harasawa, 2006; Hare, 2006; Hayhoe, 2006; Lanchbery, 2006; van Vliet & Leemans, 2006;
	Impacts on unique systems	Ecosystems	Local to regional	Smith et al., 2001; Hare, 2003; Schneider & Lane, 2006
	Forest fires; forest collapse (lack of water	Ecosystems		Harasawa, 2006; Hayhoe et al., 2006; Lewis et al., 2006
	Coral reefs	Ecosystems, tourism	Local, regional	Keller et al., 2005; Steffen et al., 2006
Human	Access to food/land productivity	Agriculture	Local, global	Parry et al., 2001; Parry, 2004; Challinor et al., 2006; Harasawa, 2006; Hayhoe et al., 2006; Steffen et al., 2006
	Access to water/Water resource stress	Water	Local, global	Parry et al., 2001; Arnell, 2006; Hare, 2006; Hayhoe et al., 2006; Nyong & Niang-Diop, 2006; Steffen et al., 2006
	People suffering from hunger	Food	Local, global	Parry et al., 2001; Hare, 2006
	Deaths from heat waves	Health	Local	Kovats et al., 2005; Hayhoe et al., 2006; Poumadere et al., 2005; Steffen et al., 2006
	Chronic sicknesses (such as allergies)	Health	Local	Gupta & van Asselt (eds.), 2004
	Other infectious diseases – Lyme; cholera; malaria	Health	Local	Harasawa, 2006; Nyong & Niang-Diop, 2006
	Malaria	Health	Local	Parry et al., 2001
	Navigability of rivers	Transport	Fluvial	Gupta & van Asselt (eds.), 2004
	Bathing water quality	Tourism	Local	Gupta & van Asselt (eds.), 2004
	Coastal wetlands	CZM	Local, global	Hare, 2006
	Coastal flooding	CZM	Local, global	Parry et al., 2001
	Abandonment of Small Island States		Global	Barnett & Adger, 2003

An African study shows that given Africa's average harsh physical environment (including very arid regions and very wet coastal areas) combined with existing socio-economic stresses (poverty, AIDS, poor governance, etc.), climate change increases African vulnerability with regard to water resources, agricultural productivity, health (not so much heat waves as is the case in the developed countries, but cholera and malaria), and ecosystems. It argues that Africa has one of the lowest adaptive capacities in the world and will therefore be most hard hit (Nyong & Niang-Diop, 2006).

A study of East and Southeast Asia discusses observed and predicted impacts in a range of areas, including extreme events, vegetation, coastal zones, health, industry, energy and transport (Harasawa, 2006). It summarizes some of the main vulnerabilities of this region, which despite significant adaptive capacity still could suffer severe impacts.

An earlier study of the Netherlands (Gupta & van Asselt (eds.), 2004; Gupta & van Asselt, 2006) indicated that the key challenges for the Netherlands were in the area of water, global ecosystems, health, coastal zone; while tourism was likely to increase (see also Chapter 1).

Table 2.4. Selected indicators used in regional and national studies.

Indicator	Sector	Scale	Used by
The number of *Elfstedentochten* (skating events)	Tourism	National	Gupta & van Asselt (eds.), 2004
Rate at which the beach disappears	Tourism	Local, global	Gupta & van Asselt (eds.), 2004
Coastal wetlands	Ecosystems	Local, regional	Hare, 2006
Impacts on coastal communities	CZM	Local, global	Schneider & Lane, 2006
Productivity of land	Agriculture	Local	Harasawa 2006; Nyong & Niang-Diop 2006
Extreme events	Economy/Health/ Agriculture	Local, national	Smith et al., 2001;, 2001

2.5.2 Five numeraires

The 1996 IPCC report on impacts essentially focused on economic costs and benefits (Pearce et al., 1996). There was a major response against valuing life in terms of dollar values (e.g. Gupta, 1997) and since then there has been a discussion to include different types of valuing units. Addressing this critique, five numeraires for measuring impacts have been proposed in the literature (Schneider et al., 2000). These are:

- Market losses – $ per ton Carbon;
- Physical losses – human lives lost persons per ton C;
- Biodiversity loss – species lost per ton C;
- Distributional effects – Income redistribution per ton C;
- Quality of life changes (heritage sites lost per ton C; forced migration per ton C; disturbed cultural amenities per ton C; etc.).

Arguably, inequitable biases that creep into analyses through a discussion of only economic values could be taken care of through such a system. For example, such a system of multiple metrics would take into account impacts on Bangladesh that in terms of global GDP could be regarded negligible, but would nevertheless lead to a large disruption of the Bangladesh society (Schneider & Lane, 2006). Lane et al. (2005) further suggest that some of these metrics should be assessed in a relative fashion (e.g. market losses relative to a country's GDP).

2.5.3 Reasons for concern

The IPCC 'reasons for concern' figure (Smith et al., 2001;, 2001) is one of the ways in which climate impacts have been categorized. The so-called 'burning embers' figure distinguishes the following five categories:

- Risks to unique and threatened systems;
- Risks from extreme climate events;

- Distribution of impacts;
- Aggregate impacts;
- Risks from future large-scale discontinuities.

The figure clearly shows that even at low levels of warming, there will be negative impacts for some, while, as the temperature increases there will be negative impacts for all. It also shows that for low levels of temperature rise, the majority of the people will be adversely affected, and at higher levels of temperature rise, there will be a negative impact on all metrics, i.e. including in terms of economic damage.[18] Mastrandrea and Schneider (2004; 2006) take the IPCC figure further, and argue that the different colour gradients cannot only be seen as an increase in the scale or intensity of physical impacts, but also as an increase in society's perception of what is dangerous. As a consequence, with increasing temperature levels, more and more stakeholders would perceive that certain thresholds are being crossed. Although they do not posit that this approach is the 'one and only' approach leading to a definition of dangerous anthropogenic interference, they do claim that it may represent some stakeholder assessments, and that it may form one way to aggregate different assessments of dangerous.

2.5.4 Key vulnerabilities

In its upcoming Fourth Assessment Report (AR4), the IPCC intends to work through the concept of 'key vulnerabilities', which are "a product of the exposure of systems and populations to climate change, the sensitivity of those systems and populations to such influences, and the capacity (…) to adapt to them" (Schneider & Lane, 2006: 13). Through key vulnerabilities, guidance can be obtained as to what level of climate change can be considered dangerous. Key vulnerabilities can refer to vulnerable systems, but also to the impacts on such systems, or to what causes these impacts.
For assessing and defining these vulnerabilities, six criteria are provided (Schneider & Lane, 2006):

- Magnitude;
- Timing;
- Persistence and reversibility;
- Likelihood and confidence;
- Potential for adaptation;
- Distribution;
- Importance of the vulnerable system.

An advantage of adopting the 'key vulnerabilities' approach could be that if dangerous is to be defined through a negotiating process, this approach could help countries formulate what they consider dangerous for themselves (Patwardhan & Sharma, 2006). It thereby deals with the problem that climate change is not always the sole causal factor for some socio-economic impacts.
Quantitative assessments of different vulnerabilities have been undertaken (for references, see Schneider & Lane, 2006). One of the ways to do this is through the so-called 'five numeraires' (see above).

2.5.5 Thresholds for specific impacts

The next question is then 'how much'; or when is a dangerous threshold crossed for a specific impact. Let us first look at how the literature measures impacts. The impacts can be gradual, passing through an unacceptable threshold for social actors, or they could occur in steps and beyond a point lead to unacceptable impacts (Patwardhan et al., 2003: 4). The formulae that the literature appears to be suggesting is that in order to define when an impact becomes

[18] Note that the text accompanying the figure states that "[t]hese temperatures should be taken as approximate indications of impacts, not as absolute thresholds".

dangerous, it is important to know what the impact is, what the probability of such an impact is, and to understand the ability of the human or natural system to adapt to that this risk.[19] For any specific impact, the threshold of when it becomes dangerous will be context-relevant and hence will differ from place to place. Furthermore, while some thresholds (e.g. biological thresholds) may be quite clear, others may be more ambiguous (Yamin et al., 2006).

The literature makes a difference between 'systemic thresholds' and 'normative thresholds'.[20] While discussions on the systemic limits usually are on a regional or global scale, the discussion of normative or legal limits are focused on perceived impacts on nations. Brooks et al. (2005: 8) point out that both types of thresholds are relevant: "[d]angerous thresholds may, therefore, be associated with continuous climate change that is detrimental to society, as well as with abrupt change".

Many argue that the geophysical limits are a universally applicable standard for determining when climate change becomes too dangerous for society. Patwardhan et al. (2003) put it as follows: "[i]t is very likely that the irreversibility and scale of such changes would be considered 'unacceptable' by virtually all policy-makers and would thus qualify as 'dangerous' change ". Oppenheimer seems to agree: "Nevertheless, value judgements may converge more for such risks than for others that are of lesser scope and magnitude, and that are to some degree reversible (…). Accordingly, the risk of deglaciation of Greenland or West Antarctica provides a promising point of departure for framing a definition of 'dangerous' anthropogenic interference with the climate system" (Oppenheimer 2005: 1406). Similarly, the critical CO_2 concentration at which a transition from source to sink of the land occurs, which could accelerate human-induced climate change, could be used to define dangerous (Cox et al., 2006).
The European Climate Forum Symposium in Beijing in 2004 argued that there are three types of dangers, and accordingly provided a classification (Hare et al., 2004):

- Determinative dangers: this refers to dangers that may be sufficient on their own to define dangerous levels of climate change with respect to Article 2. Examples mentioned include:
  - Impacts that lead to global and unprecedented consequences;
  - Extinction of 'iconic' species or loss of entire ecosystems;
  - Loss of human cultures;
  - Water resource threats;
  - Loss of sovereignty because of sea level rise;
  - Substantial increase in mortality levels;
  - Loss of food security;
  - Large-scale displacement of people;
  - Exacerbation or regional conflicts or disputes;
  - Large-scale damage to infrastructure and threat to human lives;
- Early warning dangers: This refers to dangers that are often already clearly occurring in some places, and are likely to spread and increase in severity with increased warming (e.g. impacts in the Arctic region – see ACIA, 2004; Hassol & Corell, 2006).
- Regional dangers: this refers to often large risks at a regional level, which may not be seen as dangerous from the point of view of other regions.

Yamin et al. (2006: 88) argue that "[f]ocusing on 'tolerable levels' of climate change as a way of defining the long-term goals of the UNFCCC shifts the focus away from scientists making expert judgements about 'dangerous' on the basis of crucial but rather unexplained assumptions about the choice of scale to be applied". Gupta (2005; 2006) has speculated that selecting systemic limits to determine when climate change may become dangerous might already imply a doom scenario for some developing countries (in particular small island developing states); and dangerous climate change for others (those dependent on monsoons; those with glaciers etc.). In general, it can be argued that when evaluated at a finer scale, certain impacts will be perceived as 'dangerous' sooner than when evaluated at a global scale (Yamin et al., 2006).

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[19] The probability of adverse climate impacts depends on the vulnerability of a system to this type of impact (Brooks et al., 2005).
[20] Patwardhan et al. (2003) make a similar distinction between 'Type I' and 'Type II' thresholds.

With regard to the 2ºC above pre-industrial levels-target that the European Union adheres to, the European Climate Forum stated that “even global temperatures rises below 2°C can not be considered as ‘safe’, given the large uncertainty in some of the thresholds” (Hare et al., 2004). Although they did not specify which impacts could be regarded as ‘unsafe’ specifically, the statement gives the warning that by setting a specific temperature threshold, the impacts that occur even if this threshold is crossed may be neglected (Corfee-Morlot et al., 2005). These impacts include the risks posed by climate variability (Brooks et al., 2005). Apart from the more obvious impacts on small island states and coastal communities worldwide, health impacts will pass thresholds for most countries in the world long before 2ºC. As Kovats et al. (2005: 1415) indicate, “climate change will cause continuous changes in numbers of deaths (…) upon which thresholds (or acceptable limit) must be imposed”. Stott et al. (2004: 613), with respect to the European heatwave of 2003 even state that “it is difficult to avoid the conclusion that potentially dangerous anthropogenic interference in the climate system is already underway”. Lanchbery (2006), examines impacts on ecosystems and finds that below 2ºC there already may be heavy damage to ecosystems. Folkestad et al. (2006) note a range of impacts on the Arctic that would occur with a 2ºC scenario. Warren (2006) lists a range of impacts that could also occur with or below a 2ºC temperature rise above pre-industrial levels. However, few authors go beyond the systemic limits to consider these aspects. An exception is the proposal of Yamin et al. (2006) to focus on ‘tolerable’ levels of climate change. Although they do not propose to set these levels so low that all possible risks are taken into account, they do propose to explicate that such risks exist.

Pachauri (2006) and many legal scholars argue that in determining dangerous climate change it is important to adopt some universal principles, such as basic human rights.[21] Pachauri also argues in favour of inter- and intragenerational equity. Schneider and Lane (2006: 13) similarly argue that “[f]rom an equity perspective it can be argued that any climate change that has a greater impact on those who contributed the least to the problem is less just and thus arguably more dangerous ”. In this sense, it is important to remember that the effects of climate change are expected to be the most severe in developing countries, increasing the disparity in well-being between developed and developing countries. Also, for some indigenous groups, the impacts of climate change may already breach a ‘right to avoid danger’ (Adger, 2004).[22] However, the question is then how can different ‘rights’ be compared and balanced (Adger, 2004)?

In order to avoid a situation in which defining dangerous ends up in an exercise of power, it is “critical that the negotiation of ‘dangerous’ levels of climate change be opened to multiple voices and multiple perspectives, including the broader global public, as the dangers depend literally and figuratively on where one stands, while the solutions will the coordinated action of us all.” (Leiserowitz, 2005: 1441). “Dangerous climate change is thus both politically defined and ideologically constrained” (Carvalho & Burgess, 2005).

2.5.6 Risk research

Risk research looks at, amongst others, how risk is defined in society, how public perceptions are shaped, examines social and cultural processes that change the way risk is perceived, and how risks are communicated (Lorenzoni et al., 2005).

Dessai et al. (2004) argue that there are two ways of defining dangerous climate change, an ‘external’ definition, and an ‘internal’ one. The former is constructed by scientists, on the basis of risk analyses (‘danger as defined’). The latter refers to experiences and perceptions of danger by individuals or groups of people (‘danger as experienced’). This approach argues that both definitions are relevant in providing guidance for climate policy. To examine both the

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21 Pachauri (2006: 3) states that “[w]e need to be concerned with the rights of every society. Every community on Earth should be able to exist in a manner that they have full rights to decide on.”

22 Adger (2004) discusses the right of indigenous groups in the Arctic to keep cold.

internal and external elements of 'dangerous', the approach calls for innovative methods. This includes looking at the perception of experts (Arnell et al., 2005); the public at large (Leiserowitz, 2005; Lorenzoni et al., 2005; Yamin et al., 2006); stakeholder assessments (Gupta & van Asselt (eds.), 2004; Gupta & van Asselt, 2006) and the press (Carvalho & Burgess, 2005; Smith, 2005).

A study in the US of internal risk perceptions shows that most Americans see climate change as only a moderate risk; and see the problems mainly occurring in far off places and in the future. Within the American public, risk perceptions range from those who see climate change as an imminent problem to the 'naysayers', who are not convinced that anthropogenic influences are affecting the climate. Consequently, perceptions on what is 'dangerous' will also vary to a great extent. However, although the 'naysayers' only constitute 7% of the US adult population, it is a politically powerful group (Leiserowitz, 2005). In general, Lorenzoni et al. (2005: 1390) argue that for many the definition of dangerous not only refers to longer term climate impacts, but rather to the loss of wealth as a result of mitigation measures.

An expert survey to understand whether experts think the THC may collapse (which had a high percentage of non-participation) was not able to come up with any definite answers, as there was a great variety in the responses, and because the sample of experts is inherently small (Arnell et al., 2005).[23] As a result, it is very difficult to establish what is dangerous through such a method.

A British study shows that perceptions in the UK were strongly influenced by political framings of the climate change problem by political leaders (Thatcher, Blair) and by the ideologies of the newspapers (Carvalho & Burgess, 2005). At the same time, the papers were influenced by their prejudices in favour of some sciences and against others. Many admitted that they did not have much respect for the social sciences and were less likely to cover social science research in contrast to natural science research. Their preference for telling stories over issues shapes the way the narratives are presented to the public and as such facts, ideologies, values, interests get blended together making a mockery of the idea of the "detached" journalist (Smith, 2005).

2.6 Legal interpretation of Article 2 UNFCCC

Some legal scholars have attempted to approach Article 2 UNFCCC from the perspective of international law (e.g. Bodansky, 1993; Ott et al., 2004; Yamin & Depledge, 2004). However, it should quickly be added that given the nature of Article 2, any legal interpretation would need to be informed by scientific information, notably the information made available through the IPCC.[24] For example, scientific evidence could provide an indication when ecosystems cannot adapt naturally anymore (Lanchbery, 2006).[25]

Article 2 can be compared to other environmental standards-based approaches, as it sets a standard up to which anthropogenic interference is allowed (Yamin et al., 2006). Yamin and Depledge (2004) argue that the provision has a preventative nature, based on the part referring to allowing ecosystems to adapt naturally. This could imply that delaying emissions reductions would run counter to the ultimate objective. However, Ott et al. (2004: 39) argue that by its very nature, Article 2 has no "real, legally binding force for itself". However, they admit that in combination with more specific obligations, Article 2 can be given teeth.

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23 Nevertheless, Arnell et al. (2005: 1428) state that the perceived likelihood by experts of either THC collapse or accelerated climate change is well under 10%.

24 As the IPCC reports are approved by countries' governments, this gives additional weight to using them in providing an interpretation of Article 2.

25 This is also the approach that Hare (2006) seems to be undertaking, focusing on all three conditions mentioned in Article 2.

Referring to Rowbotham (1996), Ott et al. argue that there are two legal interpretations of Article 2: "The expansive interpretation presupposes that anthropogenic interference with the climate system definitely has a dangerous nature, whereas the restrictive interpretation of Art. 2 takes first of all into account, that there is no definition, and that such a lack of definition is only consistent in the light of a lack of consensus on the standard of 'dangerous anthropogenic interference' (Ott et al., 2004: 39). On the basis of the narrow interpretation, a definition has to take place through negotiations, even though this entails considering the political feasibility of long-term climate goals. According to them in these negotiations, there should be room for ethical reflections, and human rights should be taken into account.

2.6.1 Domestic and international climate change litigation

One way to counter the exercise in power is to take recourse to litigation both in domestic courts as well as international courts. Through litigation, it is possible that a more pragmatic elaboration of what is considered 'dangerous' could occur. This could either be a direct interpretation of Article 2 by an international or national court and its direct application to a specific case, or it could take place by judgments which indicate what is considered to be unacceptable in legal terms.

The no-harm principle is a respected principle in international law. In the environmental field, it acquired legitimacy by being adopted within Article 21 of the Stockholm Declaration of the UN Conference on the Human Environment in 1972, and subsequently as Principle 2 of the Rio Declaration on the Environment and Development. It is repeated in the Preamble of the UNFCCC.

If we look at the recent literature there appears to be a rise in possible arguments for a potential case before the International Court of Justice (ICJ). It has been argued that the ICJ will not be inclined to intervene in an on-going negotiation process at international level, unless it can be demonstrated that at least some parties are not negotiating in good faith. Gillespie (2004: 107) argues that this may indeed be the case, especially when viewed from the perspective of Small Island Developing States, given the limited time frame in which climate change is to be confronted. There may thus be an opportunity for Small Island States to approach the ICJ directly or they could approach the ICJ indirectly via the UN General Assembly for an advisory opinion[26] on climate change, arguing that the negative impacts of a slow negotiating process on the small island States can be potentially disastrous. There are of course risks in that past decisions of the ICJ may not help one predict how it may judge in such a case. Jacobs (2005) analyses what would happen if a small island State, such as Tuvalu tried start a procedure against the US before the ICJ. She argues that there might be jurisdictional problems since the US could refuse to consent to the court's jurisdiction. But if such jurisdictional problems were overcome, Tuvalu could only possibly win the case if it can demonstrate successfully that the US wrongfully caused or will cause damage to Tuvalu. At present, such analyses are academic and few of the small island States are contemplating such litigation, although some are following the literature quite closely. However difficult such litigation may be, there may be no choice for some of these countries except to go to court to seek justice. Verheyen (2005) submits on the basis of four case studies of Nepal, Bhutan, the Cook Islands and China, that it may be possible to seek justice at the international level on the basis of the argument of state responsibility and international liability for injurious consequences for acts not prohibited by international law. She argues that to prove causation, courts may be willing to adopt the balance of probabilities test. She argues that even if all (potential) defendants are not included in a suit, a court may be in a position to determine joint and several liability and the courts may, in the future, be willing to look at enhanced risk as opposed to actual damage.

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[26] However, this would imply that the small island States would have to convince two-thirds of the members to agree with them; and the advisory opinion that may emanate from the ICJ would be more of legal advice than relief.

2.6.2 Litigation in the US

Since it became evident that the US was unlikely to ratify the Kyoto Protocol in the short-term, there has been a more active search for litigation opportunities within the US.

One of the legal issues revolves around the authority of the US Environment Protection Agency (EPA) to regulate carbon dioxide (CO_2) as a pollutant; and whether it is under a statutory duty to regulate it. In 2003, Massachusetts, Connecticut and Maine initiated litigation against the US EPA. The petitioners submitted that CO_2 is a pollutant. In making this argument, the petitioners cited previous statements of the EPA in which it had seen the gas as a pollutant, and further submitted that the potential impacts of climate change could be substantial on the three petitioner States.[27] This case set a precedent since it was the first time that a US State was suing the federal government on global warming. Subsequently, this case was withdrawn and the plaintiffs decided to challenge on a different case (Meltz, 2005).

This other case was about whether EPA had authority to regulate emissions from new motor vehicles. The petition was based on the argument that motor vehicles emit a pollutant that contributes to air pollution and could put human health at risk. Although the petition was made during the Clinton Administration, the decision was ultimately taken under the Bush Administration. The new EPA General Counsel issued a memo in 2003 stating that the Clean Air Act (CAA) does not give any authority to the EPA to regulate greenhouse gases in order to address the global impacts. The memo made the point that all mention of greenhouse gases under the CAA is only geared at greater research and understanding and not at regulating GHGs and that the CAA is based essentially on the concept of ambient air quality standards and is thus not suited to deal with global warming.[28]

The question that remains is whether federal law pre-empts State controls over greenhouse gases with respect to mobile sources. However, it is argued that nothing prevents States from taking measures with respect to greenhouse gases from stationary sources (Meltz, 2005).

2.6.3 Greenhouse gases could have 'significant environmental effects'

At the other end of the globe, similar debates are taking place. In an Australian case, several NGOs argued that a minister did not have the authority to prevent a planning body from examining the GHG emissions from a mine expansion project before it decided to approve the decision.[29] The Victoria Civil and Administrative Tribunal ordered in favour of the plaintiffs. Although this was an administrative law question that focussed more on the power granted in legislation, the Tribunal noted that:

> *"Many would accept that, in present circumstances, the use of energy that results in the generation of some greenhouse gases is in the present interests of Victorians; but at what costs to the future interest of Victorians? Further the generation of greenhouse gases from a brown coal power station clearly has the potential to give rise to 'significant' environmental effects."*

Another recent Australian case refers to the damage potentially caused to the Great Barrier Reef by climate change. In July 2005, the Wildlife Preservation Society of Queensland-Prosperine/Whitsunday Branch instituted legal proceedings against the Australian Government

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27 108 Complaint 06-04-03 (June 4, 2003) Commonwealth of Massachusetts, State of Connecticut and State of Maine, plaintiffs versus Christine Todd Whitman, in her capacity as Administrator of the United States Environment Protection Agency.

28 Memorandum on EPA's Authority to Impose Mandatory Controls to Address Global Climate Change under the Clean Air Act, from Robert E. Fabricant, General Counsel to Marianne L. Horinko Acting Administrator (28 August 2003).

29 *Australian Conservation Foundation v. Minister of Planning* (2004), 140 LGERA 100, found at <www.austlii.edu.au/au/cases/vic/VCAT/2004/2029.html>.

for not taking into account the potential impacts of global warming on a highly sensitive ecosystem - the Great Barrier Reef and the Wet Tropics of Queensland World Heritage Sites.[30] However, the Minister argued that he had taken the impacts of climate change into account but did not think that the mines could have a significant impact on the Reef. The discussion then took a technical turn to discuss what was a significant impact. The judgement is at present pending.[31] In a separate report it is argued that the coral reefs in Australia are seen as a world heritage and the non-ratification of the Kyoto Protocol is seen as amounting to a violation of the World Heritage Convention.[32]

2.6.4 Legal action in developing countries

Interestingly, there is also climate change related litigation ongoing in several developing countries that have ratified the Kyoto Protocol, such as Nigeria. In June 2005, various Niger River delta communities began legal proceedings against the oil companies working in the delta area and the Nigerian Attorney General requesting them to stop flaring gas as such activities leads to the emission of over 70 million tonnes of CO_2 annually. They stated that these activities constituted a violation of the fundamental right to life and dignity of human beings under the Constitution of Nigeria of 1999, are a violation of the right to live in dignity and enjoy the best attainable state of physical and mental health, and a violation of the right to a satisfactory environment favourable to their development. They further argued that provisions of the Nigerian Environmental Impact Assessment Act were contravened since no environmental impact assessment was carried out as required.[33] Since then, the original case was withdrawn for strategic reasons and separate cases were filed in different Nigerian States where the gas flaring is taking place. In one of these cases, the Nigerian Federal High Court has ruled in favour of the plaintiffs and ordered that the gas flaring must be halted.[34] Shell Nigeria has appealed the decision, and subsequently, a contempt of court proceeding against Shell and the Nigerian National Petroleum Corporation has been filed as the flaring has continued despite the court order.[35]

2.6.5 Inter-American Commission of Human Rights

Internationally, a case has been initiated by the Inuit Circumpolar Conference before the Inter-American Commission of Human Rights. It cites moderate case greenhouse gas emission scenarios and their potential impacts on the Arctic, and claims that these impacts will disrupt and possibly destroy the culture and economy of Inuit peoples. They argue that as the US is the largest contributor of greenhouse gas emissions in the world and as it has been unwilling to participate in the Kyoto Protocol, it has allegedly violated its international environmental law obligations in terms of not causing harm to other countries and peoples and has violated the human rights of the Inuit people, both under national and international law. The petitioners

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30 *Wildlife Preservation Society of Qld Proserpine/Whitsunday Branch Inc v Minister for Environment and Heritage & Bowen Central Coal Management Pty Ltd & Coal Pty Ltd*- (Federal Court proceedings No.QUD216, 2005), found at <http://www.climatelaw.org/media/Australia.emissions.suit>.

31 This update is based on email correspondence with Kirsty Ruddock of the Environmental Defender's Office North Queensland.

32 'Global Climate Change and the Great Barrier Reef: Australia's Obligations Under the World Heritage Convention: A report prepared by the Sydney Centre for International and Global Law' (Faculty of Law, University of Sydney, Australia, 2004), found at <http://www.cana.net.au/SCIGL_greatbarrierreef_Final_Report_210904.pdf>.

33 *Barr. Ikechukwu Okpara et al. v. Shell Petroleum Development Company of Nigeria Limited, et al.* (Suit No. FHC/CS/B/126/2005, 20 June 2005), filed in the Federal High Court of Nigeria, in the Benin Judicial Division.

34 Decision of the Federal High Court of Nigeria in the Benin Judicial Division Holden at Court Benin City (Suit No, FHC/B/CS/53/05, 14 November 2005).

35 Contempt of court proceedings against Shell, published by Climate Justice Programme (16 December 2005), found at <http://www.climatelaw.org/media/nigeria.shell.contempt.dec05>.

based their case as a violation of human rights under the American Declaration of the Rights and Duties of Man.

In the meanwhile, Nepal, Belize and Peru have petitioned UNESCO to list specific domestic sites (namely Everest National Park, Belize Barrier Reef and Huarascan National Park respectively) in the List of World Heritage in Danger under the Convention on World Heritage.[36] It is anticipated that this will strengthen any future case initiated to protect these vulnerable sites at the international level.[37] On 16 February 2006, twelve NGOs from the US and Canada led by the International Environmental Law Project of the Lewis and Clark Law School in the US submitted a petition to the World Heritage Committee to list the transboundary Waterton-Glacier International Peace Park on the List of World Heritage Sites in Danger as a result of the impacts of climate change.[38]

2.7 Outstanding issues

2.7.1 Overshooting long-term targets

Some argue that we have passed the safe levels of climate change and we are now in the realm of experimenting with something we have no historic experience of. Most of the impacts can be related to a rise in the global mean temperature through a complex causal chain. Much of the literature points out that a 2ºC temperature rise may form a major threshold. However, in 2002 we already warmed 0.8 (± 0.2)ºC since pre-industrial times (Hare & Meinshausen, forthcoming). Translating this 2ºC rise in temperature to concentration levels and emission pathways is complex (Schaeffer, 2004). This depends on the sensitivity of the climatic system to the emission levels.[39] This leads Stainforth et al. (2006) to conclude that “[t]he disturbing conclusion (…) is that currently we can provide neither an upper bound on climate sensitivity nor an objective probability distribution for this quantity”. It has been reported that the climate sensitivity can be between 2ºC and 11ºC, although the probability of the higher end of this range is much lower than the lower end of this range (Stainforth et al., 2006).[40] Allen et al. (2006) point out that many policy studies still use a climate sensitivity that falls in the low end of this range.[41] This is important, because a high climate sensitivity will result in faster temperature rise and higher temperatures. Although such a scenario may be regarded as very improbable, it is crucial to know *how* improbable.[42]

Through the use of probability density functions, it is possible to relate the likelihood to exceed a certain global mean temperature change under different stabilization scenarios. Hare and Meinshausen (forthcoming) have provided such an estimation of the risk of overshooting the 2ºC target. For stabilisation of GHG concentrations at 550 ppm CO_2-eq. (~475 ppm CO_2

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36 Convention Concerning the Protection of the World Cultural and Natural Heritage (16 November 1972), Article 11.4.

37 See UNESCO danger-listing petitions presented by Climate Justice Programme (17 November 2004), found at <http://www.climatelaw.org/media/UNESCO.petitions.release>.

38 Petition to the World Heritage Committee Requesting Inclusion of Waterton-Glacier International Peace Park on the List of World Heritage in Danger As a Result of Climate Change and for Protective Measures and Actions, prepared by the International Environmental Law Project of Lewis and Clark Law School (2006), found at <http://www.climatelaw.org/media/UNESCO%20-%20Waterton-Glacier%20International%20Peace%20Park%20petition>.

39 This climate sensitivity is usually defined as the equilibrium change in global mean surface air temperature following a doubling of the atmospheric (equivalent) carbon dioxide concentration (IPCC, 2001; see also Allen et al., 2006).

40 However, this does not mean that a climate sensitivity at the higher end of this range is excluded. For comparison, the IPCC (2001) mentions an upper range of 5.8°C.

41 See, for example, Edmonds and Smith (2006), who use a climate sensitivity of 2.5ºC.

42 Allen et al. (2006) argue that a 1% chance of a >7ºC warming in response to 550 ppm could be deemed unacceptable by many, whereas a 0.001% is in the same line as the Earth being hit by a comet in the next 100 years.

stabilisation), the risk of overshooting 2ºC is between 68-99%, with a mean of 85% ('likely' in IPCC terminology). For 450 ppm CO_2-eq. (~400 ppm CO_2), the risk is between 26-78% (mean 47%). For 400 ppm CO_2-eq., overshooting can be seen as 'unlikely', with a chance of 2-57% (mean 27%). At 350 ppm CO_2-eq., the possibility is between 0-31% (mean 8%). Hence, if we wish to stay below 2ºC with a considerable degree of certainty, then concentration levels should not exceed 400 ppm CO_2 equivalent (see also Den Elzen & Meinshausen, 2006; Meinshausen, 2006; cf. Allen et al., 2006). Delaying emission reductions may result in larger temperature increases as a result of inertia in the socio-economic system (Kallbekken & Rive, 2006). Postponing of emission reductions by 10 years would already commit us to an additional 0.2-0.3ºC warming over a 100 year (Hare & Meinshausen, forthcoming).

2.7.2 Precautionary approach or not?

Article 3 UNFCCC embraces a precautionary approach by stating that "[w]here there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost". Several authors emphasise the need for a precautionary approach in defining what is dangerous (e.g. Azar & Rodhe, 1997; Hare & Meinshausen, forthcoming; O'Neill & Oppenheimer, 2002; Ott et al., 2004; Oppenheimer, 2005). Oppenheimer (2005: 1406) argues in particular that "the risk of deglaciation of the ice sheets may provide a perfect example where precaution is not merely a desirable risk management strategy, but the only plausible one, because commitment to catastrophic change could occur long before scientific understanding has solidified". Keller et al. (2005) conclude that "[a] precautionary policy to reduce the risk of a disintegrating West Antarctic ice sheet would imply to decarbonise the global energy system within this century". However, others have countered that "political inertia, economic interests and questions about the costs" inhibit such an approach (Brooks et al., 2005: 14; see also Tol, forthcoming).

If governments apply the precautionary principle and act now to mitigate, while it turns out that fears of climate change were unfounded, this can be considered a 'Type I error'. If governments do not act because there is not enough certainty, and significant adverse impacts of climate change do occur, this can be considered a 'Type II error'. Whereas scientists may tend to avoid the first type of errors, policy-makers may find it more important that the second type is avoided, and may want to enter into a hedging strategy that avoids at least those errors by determining a level of unacceptable climate change.

2.7.3 Costs

As Brooks et al. (2005: 2) put it, in order to decide on the best level and time to stabilise GHGs it is necessary to consider "the costs (including but not limited to economic costs) associated with undesirable environmental, social and economic impacts, and the related measures that will be necessary to facilitate adaptation, due to delaying action, balanced against the costs of mitigation of climate change by reducing GHG emissions". In other words, somehow the question of impacts has to be dealt with simultaneously with the question of costs of mitigation (Pachauri, 2006).

As a result, it can be argued that critical thresholds for GHG concentrations and temperature rise limits can be obtained through a cost-benefit analysis of mitigation costs and residual damage to natural and socio-economic systems (Izrael & Semenov, 2006; Tol & Yohe, 2006). According to Azar and Schneider (2002), the costs of mitigation would only delay overall economic growth by a few years over a century and could thus be considered negligible.[43] This

[43] See also Keller et al. (2005), who argue that the costs of reducing the risk of the WAIS disintegrating are not prohibitive.

leads Kuik (2004) to conclude that “mitigation cost estimates cannot be used as thresholds, in the sense of ‘this cost is clearly too high’ or ‘this cost is just acceptable’”. Nevertheless, Izrael and Semenov (2006) point out that such costs could be politically significant in the short term. In this sense, Tol (forthcoming) reflects a general perception that “stringent greenhouse gas emission reduction policy may well be very expensive”. He further argues that it could be useful to monetize avoided climate impacts resulting from emissions reductions (see also Tol & Yohe, 2006). However, this is vulnerable to the critique mentioned above that economic values do not capture the value of all that is vulnerable to climate change. In particular, there are severe problems with regard to the distribution of impacts and irreversible damages.

2.7.4 The role of adaptation

In determining what is dangerous, adaptation of social and natural systems is an important factor to take into account. The initial IPCC reports (Houghton et al., 1990) did not pay much attention to adaptation when discussing impacts. Since then, the inevitability of certain climate change impacts has pushed the balance towards a discussion of adaptation (Yamin et al., 2006). The main argument is that the extent to which natural or socio-economic systems are at risk not only depends on the magnitude, rate and nature of climatic change, but also on the adaptive capacity of these systems (Smit et al., 2001). Not taking adaptation into account exposes studies to the critique that climate change impacts are overestimated (e.g. Tol, forthcoming). However, in order to establish what is dangerous, we need to know more about when adaptation is no longer an option, either because of low adaptive capacities or because of the physical or financial limitations to adaptation as an option.

It is possible to distinguish certain definitions with respect to the limits of adaptation of social systems. On the one hand, there is ‘nonadaptation’, which is “the extent to which adaptation fails to keep pace with climate change”. On the other, there is ‘maladaptation’, “where the human response actively undermines the capacity of society to cope with climate change or further contributes to the problem” (Niemeyer et al., 2005: 1443). It is argued that it is easier for societies to adapt where there are gradual changes in society, as opposed to when the changes are rapid and abrupt (Mastrandrea & Schneider, 2001; Pachauri, 2006). According to the National Research Council, “[t]echnically, an abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause. Chaotic processes in the climate system may allow the cause of such an abrupt climate change to be undetectably small” (NRC, 2002: 14). The responses to these types of changes may well be adaptive, however, they may also be nonadaptive or maladaptive (Niemeyer et al., 2005). However, it is also possible that a relative gradual change outpaces the adaptive capacity of natural and social systems, making it more likely that such change would be considered dangerous (Brooks et al., 2005; Lorenzoni et al., 2005). As a result, adaptation and resilience-based approaches to avoiding dangerous impacts may not be sufficient to address risks that cannot be taken away by adaptation, such as the risks posed by large-scale abrupt events (Brooks et al., 2005). Corfee-Morlot et al. (2005) suggest to distinguish between near-term and unavoidable impacts, which require immediate adaptation attention; and long-term impacts, where mitigation (possibly in combination with adaptation) can play an important role. To achieve this distinction, impacts need to be better related to time frames.

Dessai et al. (2004) distinguish between top-down and bottom-up methods for defining ‘dangerous’. They argue that in top-down methods, based on scenarios and models, adaptation is rarely taken into account,[44] whereas adaptive capacity is usually included – implicitly or explicitly – in bottom-up studies.

The desire to include adaptation in determining when an impact is dangerous is an anomaly in public policy. It has been introduced to lower the costs of emission reduction efforts. However,

[44] This point seems to be confirmed by Warren (2006).

the costs and effectiveness of adaptation are not yet clear (e.g. Hitz & Smith, 2004). Poor people adapt less easily than rich people and this may mean that this group is not helped. Small Island States could be completely submerged if the sea-level rises by 1 or 2m and there is only a small set of adaptation options, which is becoming smaller over time (Barnett & Adger, 2003). Besides, some ecosystems do not adapt easily. As Lanchbery (2006) explains: “Any particular system consists of an assemblage of species, some of which are near the edges of their ranges and others that are not. Those at their range edges will tend to move as their climate space changes whereas those nearer their range centers need not. This differential movement will be exaggerated by opportunistic, robust species tending to move more rapidly and faring better when they do. The composition of ecosystems, and the ecosystems themselves will thus change.”

There are reports that helping communities adapt may not be so easy and thus although the desire to include adaptation in the measure of when climate change is dangerous is an understandable one, it is difficult to predict.

2.8 When is climate change dangerous? An overview of proposals

Even though Izrael and Semenov (2006) argue that the scientific process with regard to Article 2 is ongoing, they also indicate that it may be a good idea for scientists to explicate tentative thresholds based on expert judgment, as the public and policy discussion on this topic has already started. Different authors use a range of arguments and approaches in order to define when climate change may become dangerous. An overview of proposals for thresholds can be found in Table 2.4. Sometimes, the proposals are linked to specific vulnerabilities, such as the disintegration of the West Antarctic Ice Sheet, the shutdown the thermohaline circulation, or the loss of species and ecosystems. However, not all authors make clear on what basis they choose a specific threshold and refer, for example, simply to ‘current scientific knowledge’. It should be noted that in most of the studies mentioned below, the authors have provided their rationale for proposing a target. This could be a reference to the precautionary approach, weighing the uncertainties, or their expert judgment.

Table 2.4. Overview of proposals for thresholds

Vulnerability	Threshold	References
Shutdown of THC	3ºC above 1990 levels in 100 years; 450 ppm CO_2; 25% probability with carbon tax; 50% probability with no policy intervention	O'Neill & Oppenheimer, 2002 Schlesinger et al., 2006
Disintegration of the WAIS	2ºC above 1990 levels; 450 ppm CO_2 (probably, but not certainly)	O'Neill & Oppenheimer, 2002; Oppenheimer, 2005
Complete or partial disintegration of the GIS	1ºC above today's levels; 2.7ºC local Greenland warming	Hansen, 2005: 276; Lowe et al., 2006; Nicholls & Lowe, 2006
Severe damage to coral reef systems	1ºC above 1990 levels; <450 ppm CO_2	O'Neill & Oppenheimer, 2002
Ecosystems/species loss	2ºC (to avoid worst damage to species and ecosystems); 1.5ºC above pre-industrial levels; and 0.05ºC per decade or 0.5ºC per century 1ºC risks low except for specific species; 2ºC risk of severe damage or losses	Lanchbery, 2006 Van Vliet & Leemans, 2006 Hare, 2006
Arctic	Local temperature rise of 4ºC above pre-industrial levels	Izrael & Semenov, 2006
Absolute sea-level rise	1m above pre-industrial levels	Izrael & Semenov, 2006
Not related to specific vulnerability/No vulnerability mentioned		
	550 ppm CO_2	EC 1996; 2005; Izrael & Semenov, 2006; RCEP, 2000
	2.5ºC above pre-industrial levels	Izrael & Semenov, 2006
	2ºC above pre-industrial levels	Azar & Rodhe, 1997; CAN, 2003; EC 1996; 2004; Grassl et al., 2003; ICCT, 2005
	<2ºC above pre-industrial levels	Hare et al., 2004
	0,1ºC per decade	CAN, 2003
	0.2ºC per decade	Grassl et al., 2003

Based in part on Oppenheimer & Petsonk (2005)

2.9 Conclusions

Let us then draw conclusions from the literature reviewed in this chapter. First, what is inherently clear is that defining dangerous climate change is something that is highly controversial. Many scientists deny that there can be any objective method to define dangerous climate change and hence argue that the effort to do so is futile. Others argue that given the high degree of danger inherent in climate change, it is absolutely vital that efforts are made to define what constitutes dangerous climate change.

Second, although there are a number of different methods used to identify dangerous climate change, most seek to only look at some part of the entire chain from impact through concentrations to emissions to the perception of the problem. Most authors identify indicators related to certain climate impacts and very few go on to identify threshold limits. There is considerable overlap between the indicators identified in the literature. Most articles focus on one or more indicators.

Third, each discipline looks at danger differently and what is considered dangerous also differs between one person and another. In this report we try to indicate the reasons that can be given to consider a certain climate change dangerous or not.

Fourth, in the selection and assessment of indicators there are two kinds of risks. One, the choice of scale to determine risk is mainly national. At least most countries and researchers are studying this at national level. Only systemic impacts (i.e. large-scale events) are evaluated at a global level; almost all other impacts are seen purely from a national or local perspective. This may imply that impacts in other countries and regions are not taken into account to the fullest extent. The other issue is that there is a tendency to argue that since such risks are gradual, adaptation can play a major role. However, taking adaptation into account is not an easy exercise; and literature on adaptation demonstrates the numerous problems involved.

Finally, several authors argue that a 2ºC rise in temperature (or 400 ppmv CO_2-eq.) from pre-industrial levels is the level at which dangerous climate change can set in because of the potential impacts of low-probability high-impact events. However, for many sectors and for abrupt and /extreme events it is not clear if specific thresholds can be specified. Gradual change of our climate and gradual change of related impacts without a clear threshold temperature seems more likely. However, this has not stopped several authors from proposing certain thresholds. Ultimately, the discussion on what is dangerous climate change or in other words what are we willing to accepted as a society, will be determined in the political arena, on the basis of much more than only the scientific information.

3 Observed and projected climate change: globally and in the Netherlands

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3.1 Introduction

Given the new scientific results in the Netherlands and abroad, this chapter aims to provide a very brief update of the most recent information on climate change, observed trends world-wide and in the Netherlands, expected global climate change in the 21st century, expected climate impacts in the Netherlands in the 21st century, and finally it presents some illustrations of future changes expected in the Netherlands. This chapter aims to illustrate what can be expected in the future, and thereby give an indication of what climate change is more and less likely. In doing so it builds on an earlier assessment for the Netherlands and anticipates some of the results to be reflected in the 2007 fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC).

3.2 Current scientific knowledge on human influences on climate

The section below focuses on some of the most recent information regarding CO_2 level, climate sensitivity, the thermohaline circulation, and melting of ice in Greenland and the West Antarctic Ice Sheet.

3.2.1 Current CO_2 level

The current CO_2 level is about 380 ppm, compared to a pre-industrial level of around 270-290 ppm. The CO_2 equivalent summarises the climate effect (‘radiative forcing’) of all human-induced greenhouse gases, tropospheric ozone and aerosols, and the current CO_2 equivalent is clearly above 400 ppm. According to Meinshausen (2006) and Schneider & Mastrandrea (2005) limiting warming to 2°C above pre-industrial levels with a relatively high certainty (>50%) requires the equivalent concentration of CO_2 to stay below 400 ppm. If concentrations were to rise to 550 ppm CO_2 equivalent, then they consider it unlikely that the global mean temperature increase would stay below 2°C (see also Chapter 2).

3.2.2 Climate sensitivity

Hegerl et al. (2006) determined that the climate sensitivity (the increase of global temperature in case of doubling the CO_2 concentration) lies with 90% probability between 1.5- 6.2 K. There is still a lot of discussion about the possible range of climate sensitivity, and how it can be constrained. Some publications show an increase of the average climate sensitivity (Hare & Meinshausen, 2006), whereas other publications (Annan and Hargreaves, 2006) show relatively low sensitivities in the ‘traditional range’ of the IPCC (2001).

3.2.3 Thermohaline circulation

Gregory et al. (2005) show that GCM climate projections simulate a slowdown of the thermohaline circulation (THC) in response to global warming over the next century, in the range of 0-50%. No GCM has shown a complete shutdown. A net cooling over land could occur with a complete shut down of the thermohaline circulation (Stouffer et al., 2006). However, in the presence of strong radiative forcing the net cooling will be small or even a net warming would occur over Europe (Vellinga & Wood, 2005). Also, a shutdown of the THC would result in changes in heat uptake and oceanic circulation, resulting in a sea level rise in the North Atlantic that exceeds the global average sea level rise by 10s of cm (Levermann et al., 2005). From recent literature it is concluded that a shutdown during the 21st century must be regarded as unlikely, and that much research is required before we can provide robust estimates of the likelihood of THC shutdown.

3.2.4 Melting of land ice (Greenland and the West Antarctic Ice Sheet)

In the IPCC's third assessment report (IPCC, 2001) the possibility of a substantial sea level rise due to instability of the West Antarctic Ice Sheet (WAIS) was considered to be very unlikely during the 21st century. And also a review of expert opinions (Vaughan & Spouge, 2002) suggested that a collapse of the WAIS is not thought likely to occur in the next 100 years. However, the simulation of the dynamics of these ice sheets is relatively poor in climate models due to incomplete scientific knowledge. Projections of the change of the Greenland and Antarctic ice sheets for the 21st century are still highly uncertain (Huybrechts et al., 2004; Gregory & Huybrechts, 2006), also because the measurements are too sparse, and time series too short to assess the acceleration rate of the contribution to sea level rise as global temperature rises.

The thermosteric component of sea level rise (increased volume of water due to increasing water temperatures) is much better understood than the changes in terrestrial water storage (sea level rise due to 'new' water of melting land ice sheets and glaciers).

Both model studies and observations indicate a positive sensitivity (decrease of land ice volume) to increasing air temperatures. However, the sign of the sensitivity for Antarctica is undetermined (negative from model simulations, positive from recent observations). For large temperature increases strong increases of melting may occur, especially for the Greenland ice sheet (e.g. Overpeck et al., 2006). Also, both the Antarctic and Greenland ice sheets may feature unstable glaciers and large amounts of calving. Accelerated ice flow in both ice sheets could dramatically increase their contributions, but quantitative projections are almost impossible to make. Climate simulations of the last interglacial period (130,000 years ago) by Otto-Bliesner et al. (2006) show that for climate conditions with a global mean temperature of +4°C compared to present-day climate (which is higher than the pre-industrial temperature) the current Greenland ice sheet could melt to about half its current size (3.4 m sea level rise), taking many centuries.

3.3 Observed trends world-wide and in the Netherlands in the 20th century

3.3.1 Introduction

This section focuses on the observed changes in temperature, precipitation, wind and gales, and sea level rise.

3.3.2 Temperature

Since 1900 the global temperature has risen on average by 0.8°C (Figure 3.1). From 1975 onwards, global temperature increased by 0.5°C. Based on comparison of model calculations and observations, it can be concluded that in the past 30 years the temperature increase was mainly anthropogenic in nature (IPCC, 2001). Temperature rise was largest above the continents in the Northern Hemisphere (Jones & Moberg, 2003).

The global temperature rise of +2°C in 2050 or in 2100 should not be confused with the +2°C that is specified by the Dutch government and the EU as the maximum admissible global temperature to avoid dangerous human disturbance of the climate system. This policy objective refers to a stabilisation of +2°C above the pre-industrial level, whereas the IPCC (and also KNMI) present changes with respect to 1990. The temperature increase between 1860-1880 and 1990 is close to 0.8°C (Figure 3.1). This means that a temperature rise of +1°C with respect to the pre-industrial level, used further on in this report, is close to the current situation.

In the Netherlands the temperature has risen, on average, by about 1.2°C since 1900 (Figure 3.1). During the past 20 years, the months February and March have seen the largest increases in temperature. Apart from global warming, this was also due to an increase in the number of days with southwesterly winds (van Oldenborgh & van Ulden, 2003). It could not be determined yet whether the observed increase of 'warm' winds is connected with the human influence on the climate, or if it is only the product of natural fluctuations.

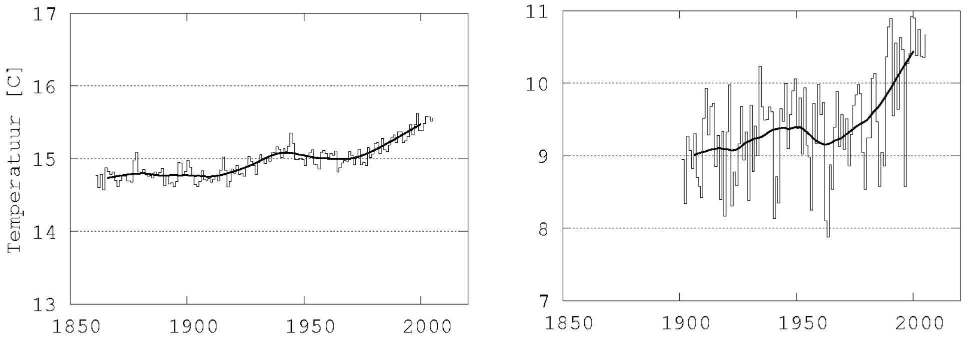

Figure 3.1. Average annual temperature on earth (left) and in De Bilt (right) between 1860 and 2005. The thick black line represents the 30-year moving average (Source: CRU/UKMO and KNMI).

3.3.3 Precipitation

In the temperate regions in the Northern Hemisphere - to which North West Europe belongs - precipitation increased, on average, by 5 to 10% in the 20th century. This increase is caused partly by the fact that warmer air can transport more water vapour. The increase in the strength of the westerly circulation has also played a role. For Europe as a whole, the intensity of extreme precipitation has increased in the past 50 years. Just as in many other regions in the world, the number of extremely wet days increased in many places in Europe (Alexander et al., 2006; Figure 3.2).

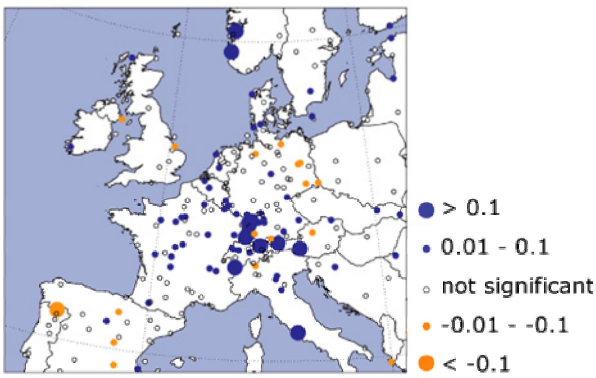

Figure 3.2. Trends in number of days per year with at least 20 mm precipitation, measured at European weather stations between 1946 and 2004 (Source: eca.knmi.nl).

In the Netherlands, the annual precipitation amount increased by about 18% from 1900. This is especially caused by an increase in winter, spring and autumn, while in the summer the precipitation amount has hardly changed. In winter, the extreme 10-day total precipitation increased over the past century (29%). No clear trend in the maximum daily precipitation in summer has been found.

3.3.4 Wind and gales

In the temperate regions, the number of gales and their strength is especially dependent on the strength and the flow pattern of the circulation in the upper air. In previous decades, above the Northern part of the Atlantic Ocean this circulation has become stronger than it was before (Yin, 2005). Besides, the flow pattern was displaced to the North. It is not clear to what degree (if at all) this change in air circulation is related to the enhanced greenhouse effect, caused by humans.

Measurements at KNMI-stations in the Netherlands show that the total number of 'gales' (≥6 Beaufort inland, or ≥7 Beaufort along the coast) has decreased since 1962. On average, these events occur about 10 times per year. At present we experience 20-40% less of such 'gales' when compared to the beginning of the sixties (Smits et al., 2005). The Netherlands is too small and the observational series too short to detect changes in the number of heavy gales (at least 10 to 11 Beaufort). These gales occur in the Netherlands too seldom for trend detection, on average less than once per year.

3.3.5 Sea level

According to measurements in coastal areas and with sea-based buoys, the sea level rose by 1 to 2 mm per year since 1900. Especially between 1930 and 1960 and in the past decade the increase was relatively large. Satellite measurements since 1993 show a global average sea level rise of approximately 3 mm per year, with strong local variations between -20 up to + 20 mm per year (Church & White, 2006; Leuliette et al., 2004). Rignot and Kanagaratnam (2006) showed, on the basis of satellite measurements, that there are variations in the melting of the glaciers at Greenland. This results in a variation in contribution to the sea level rise of 0.23 mm/year (1996) up to 0.57 mm/year (2005). Between 1993 and 2004, the sea level in the North-eastern part of the Atlantic Ocean (including the North Sea) also increased approximately 3 mm per year. Until now it could not be determined to what degree the observed acceleration of sea level rise in the past 13 years has been caused by the enhanced greenhouse effect and to what degree it can be attributed to natural fluctuations.

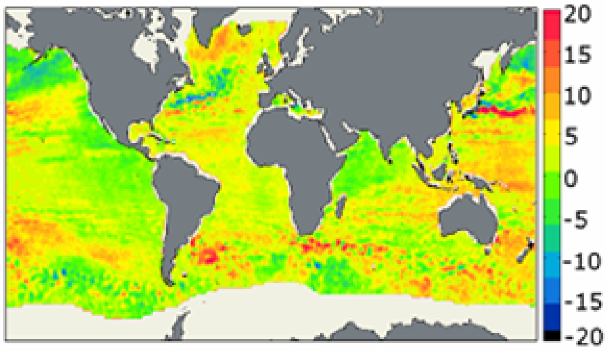

Figure 3.3. Sea level rise in mm per year between 1993 and 2004 as measured by satellites (Source: Leuliette et al., 2004).

3.4 Global climate change in the 21st century

3.4.1 Introduction

This section focuses on the anticipated changes in the global climate in the 21st century. It looks, in particular, at impacts on temperature, precipitation, wind and gales, and the anticipated rise in the sea level.

3.4.2 Temperature

The most recent climate models, that are used for the fourth assessment report of the IPCC, calculate a global mean temperature increase of 1 up to 6 °C for the year 2100, compared to 1990 (Annan et al., 2005; Knutti et al., 2006).

3.4.3 Precipitation

Climate models calculate an increase in total annual precipitation for the temperate regions and a decrease in the subtropics. However, the calculations vary considerable among themselves. For Southern Europe nearly all climate models calculate a decrease in summer precipitation and an increased chance for drought. For Northern Europe the change in precipitation is less consistent. For Europe as a whole, an increased chance of prolonged heavy precipitation and short intense showers is calculated.

3.4.4 Wind and gales

Climate models calculate, on average, a slight decrease in the number of gales at temperate latitudes in the Northern Hemisphere. Besides, there are indications that the strength of the heaviest gales increases (Lambert & Fyfe, 2006; Leckebusch et al., 2006), although these indications are very uncertain. Analyses by KNMI of the best global climate models (for circulation world-wide and above Europe) of KNMI did not show clear changes in the maximum daily windspeed per year: the year-to year variations are much larger than the trends in the models (van den Hurk et al., 2006).

For the wind climate in Western Europe it is important how global warming may induce changes in air circulation patterns. These determine the number, strength and the path followed by depressions. Therefore, they affect the future climate. Model calculations for air circulation patterns in our region vary considerably among themselves.

3.4.5 Sea level

Oceans react slowly to air temperature rise. Therefore, the sea level rise in the next few decades is rather insensitive to the rate of air temperature increase. Only after 2050 does the rate of global warming become more important.
Due to the slow reaction of the oceans, the sea level will continue to rise long after 2100, even if greenhouse gas concentrations stabilise. In addition, if large scale melting of the large ice sheets also takes place, a sea level rise of few meters within a few centuries can be expected (Otto-Bliesner et al., 2006).

3.5 The future climate in the Netherlands

Based on the most recent results from climate research, KNMI presented four new climate scenarios for the Netherlands on May 30, 2006. These scenarios will replace the scenarios that

were drawn up in 2000 for the Commission on Water Management in the 21st century (WB21 scenarios; Kors et al., 2000; Können et al, 2001). The four KNMI'06 scenarios were not chosen arbitrarily: the climate in the Netherlands will, most probably, develop between these four scenarios or "corner stones". The scenarios are developed for use by a wide range of research disciplines, making comparison and integration of results of the various disciplines easier.
A schematic overview of the new scenarios is shown below.[45]

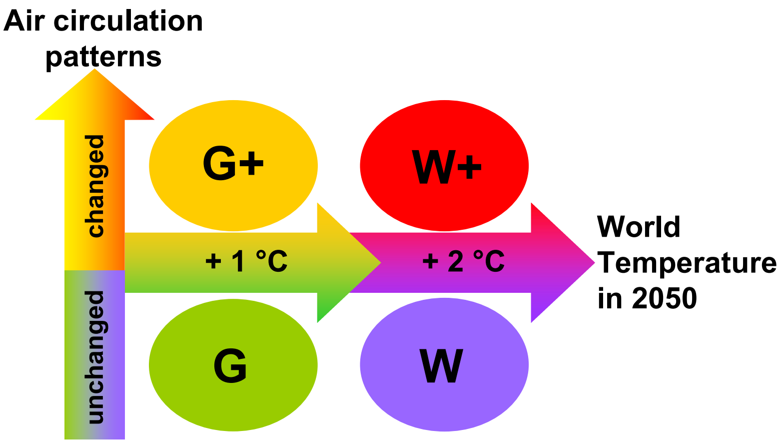

Figure 3.4. Schematic overview of the four KNMI'06 climate scenarios.

For an explanation look at the legend below.

Table 3.1. Legend for the KNMI'06 climate scenarios.

G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

* "G" is derived from "Gematigd" = Dutch for "moderate".

[45] The complete set of data for the new scenario's can be found at the KNMI-website (Dutch: www.knmi.nl/klimaatscenarios; English: www.knmi.nl/climatescenarios).

Table 3.2. Climate change in the Netherlands around 2050[1], compared to the baseline year 1990[2], according to the four KNMI'06 climate scenarios.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter [3]	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer [3]	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

[1] data on changes in 2100 can be found at www.knmi.nl/klimaatscenarios.
[2] the climate in the baseline year 1990 is described with data from the period 1976 to 2005.
[3] winter' stands for December, January and February, and 'summer' stands for June, July and August.

As in the previous generation scenarios, climate change scenarios are given relative to 1990. A note on the definition of reference and target periods is appropriate here. For the KNMI'06 climate scenarios we describe the changes in the climatological target period *around 2050* relative to a climatological baseline period *around 1990*. Both for the target and baseline period a 30 years period is used to describe the climate around 1990 and around 2050.
The selection of the four new scenarios was based, among others, on the fact that the climate change in the Netherlands depends mainly on the global temperature rise as well as on changes in the air circulation patterns in our region (West Europe) and the related changes in the wind (Van Oldenborgh & Van Ulden, 2003; Van Ulden & Van Oldenborgh, 2006). To be able to deal with the uncertainties in future climate change, KNMI selected four climate scenarios from the broad range of possible futures. For these situations, as far as possible, a complete picture of our future climate is presented. An elaborate description with all relevant sources and references to the scientific literature can be found in the KNMI-publication WR 2006-01 "KNMI climate change scenarios 2006 for the Netherlands" (van den Hurk et al., 2006).
Each of the specific scenarios is plausible. However, with our current knowledge of the climate system and of the technological and socio-economic developments it is not possible to indicate which scenario is most probable.
The following is a comparison between the WB21 scenarios and KNMI'06 climate scenarios:

- Both generations of KNMI scenarios use the IPCC projections for global temperature rise as the starting point.
- The global temperature increase of +1°C in 2050 compared to 1990 in the KNMI'06 scenarios is the same as used in the old 'central' WB21-scenario. The increase of +2°C in 2050 in the KNMI'06 scenarios is consistent with the old "high" WB21-scenario. However, de data per scenario are somewhat different due to the difference in methodologies and available data.

- In the KNMI’06 scenario's changes in air circulation patterns were included explicitly, and the relation between temperature rise and changes in precipitation was examined using a wide range of climate models and measurements. During the construction of the WB21-scenarios only the results of a limited number of climate models were available, and it was assumed that the air circulation patterns would not change.
- The WB21-scenarios assume that temperature rise in the Netherlands is the same as the global temperature rise. In the KNMI’06 scenario, temperature rise in the Netherlands deviates from the global temperature rise, especially in the scenarios with changes in air circulation.
- The rainfall events in winter will increase also in the KNMI’06 scenarios, but less than in the WB21-scenarios.
- In the KNMI’06 scenarios the absolute sea level rise is presented, whereas in the WB21-scenarios the relative sea level rise was presented (with an average ground level subsidence included).

3.5.1 What is not included in the scenarios?

The KNMI’06 climate scenarios do not account for any possible occurrences associated with abrupt climate change, for example as a result of a complete collapse of the ‘gulf stream’ or the unexpectedly fast melting off of large ice caps in Greenland and West Antarctica. The scenarios do include the effect of slow down of the ‘gulf stream’ and of increased melting rates; however very extreme and unlikely situations are not included. The simulation of these types of events is relatively poor in climate models due to incomplete scientific knowledge (among others on how fast the ice sheets can melt, how stable they are) about these phenomena. Besides, on the basis of the available observations no conclusions can be drawn about increased trends in melting. The scenarios neither include phenomena where it is not clear if they are physically realistic, such as "super" storms that are much heavier than have ever occurred in Europe.

3.6 Examples of future changes in the Netherlands

3.6.1 Number of summer days and frost days

Due to the temperature increase the number of summer days (maximum temperature >= 25°C) increases and the number of frost days (minimum temperature < 0°C) is expected to decrease. The expected increase in summer days is highest in the scenarios with changes in air circulation pattern (see Figure below). In the W+ scenario the expected increase in summer days is around 50% in 2050, compared with the climate in 1990. The decrease in frost days is also around 50% in 2050.

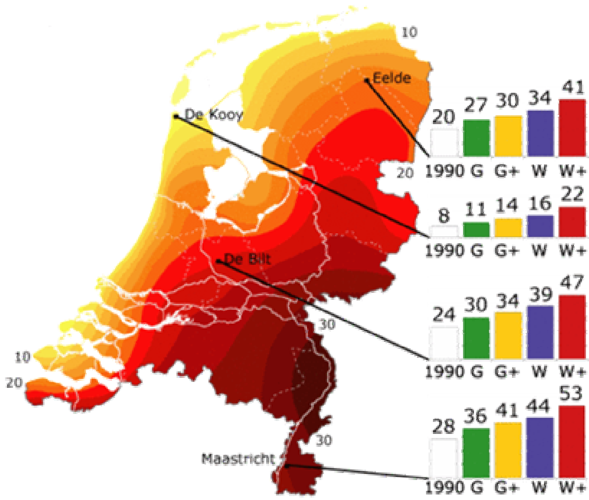

Figure 3.5. Map with the observed number of summer days (left; maximum temperature >= 25°C) per year for 1971-2000, and for four locations in the Netherlands the climate scenarios for 2050. The differences in summer days and frost days between the four locations are due to the differences in the current climate.

Table 3.3. Average number of days per year met certain temperatures around 2050 under various climate scenarios (KNMI'06 scenarios) for four locations in the Netherlands. (The data are based on transformations of the time series of 1976-2005 to 2036-2065).

Frost days (min. temp. < 0°C)	1976-2005	G 2050	G+ 2050	W 2050	W+ 2050
De Kooy	43	30	28	22	19
De Bilt	61	45	43	33	29
Eelde	70	53	51	41	37
Maastricht	60	45	42	33	29
Tropical days (max. temp. >= 30°C)		G	G+	W	W+
De Kooy	1	1	2	2	5
De Bilt	4	7	9	10	14
Eelde	4	6	7	8	12
Maastricht	5	8	10	12	17

3.6.2 Energy use for heating

Due to the expected temperature increase the energy need for heating of houses, factories and offices will decrease. The energy need for heating shows a clear relation with the number of heating degree-days (the sum of the deviations from 17°C for all days with an average temperature < 17°C; e.g. a day temperature of 14°C adds 3, and a day temperature of -3°C adds 20 degree-days). Depending on the climate scenario, the number of heating degree-days around 2050 will decrease by 9% (G+ scenario) up to 20% (W+ scenario), compared to 1990 (Figure 3.6).

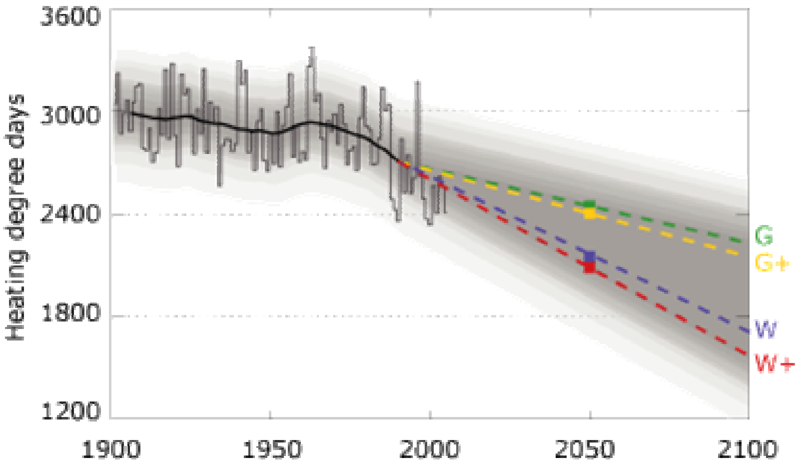

Figure 3.6. Number of heating degree-days per year in the Bilt between 1900 and 2005, and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average in the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.

3.6.3 Skating events

The chance of long periods with frost will decrease due to the expected temperature rise. As a consequence, in all four scenarios the expected number of *Elfstedentochten* decreases. In the W+ scenario, which has the strongest temperature rise as well as changes to air circulation patterns, the decrease will be strongest. The chance decreases more than could be expected on the basis of the average temperature increase only, since in this scenario the temperature of the coldest winter days increases more than the average.
In the 20th century the number of *Elfstedentochten* was 15 (with 38 'suitable'frost periods; Brandsma, 2001). In the period 2001 up to 2050 the chance of *Elfstedentochten* is reduced with about 20% (G-scenario) up to 60% (W+ scenario), compared to the 20th century.

3.6.4 Growing season

Due to the higher temperatures in winter and spring, the growing season of many plants will start earlier, a trend that has already been observed over the past decades (see www.natuurkalender.nl). A temperature of 5°C is often used as the threshold above which plants start to grow. The first day in the year at which the average day temperature reaches 5°C and after which it remains above 5°C until the first of July can be used as an indication for the start of the growing season. According to this definition, on average the growing season will start between 6 days (G scenario) and 19 days (W+ scenario) earlier in 2050 compared with 1990 (Figure 3.7)

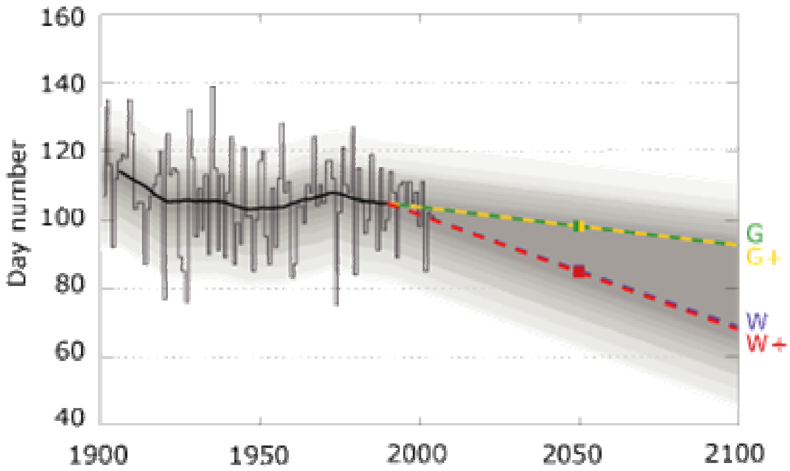

Figure 3.7. Day number in the year at which the average day temperature reaches 5°C and after which it remains above 5°C until the first of July in De Bilt between 1900 and 2005, and the four climate scenarios (coloured lines). The thick black line represents the 30-year moving average in the observations. The grey band represents the year-to-year variation, derived from the observations.

3.6.5 Chance of dry years

In 2003 the cumulative precipitation deficit (=difference between precipitation and potential evaporation) in the Netherlands was almost 220 mm (Beersma et al., 2004). Currently (for the period 1906-2000) the return time of such a precipitation deficit is about once every 10 years. In the figure below we can see that the chance of such high precipitation deficits clearly increases in the W+ scenarios. In the W scenario the return time does not change much (less than once every 6 years), however in the W+ scenario the return time will be about once every 2 years.

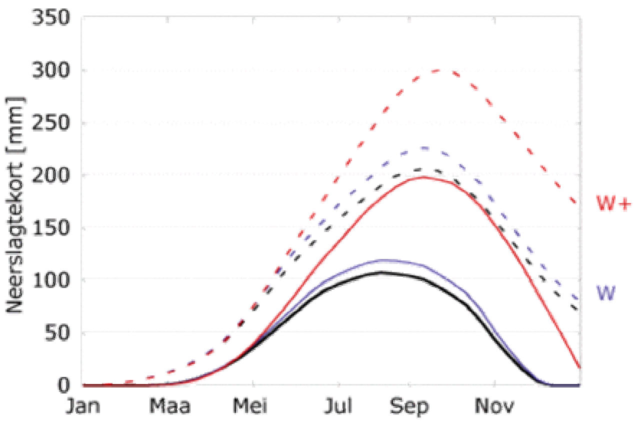

Figure 3.8. Cumulative precipitation deficit (=difference between precipitation and potential evaporation) in the Netherlands (average 13 stations) for the historical climate (1906-2000; black), and two climate scenarios for 2050 (W and W+). For each date, the continuous lines represent the maximum precipitation deficit that is reached in 50% of the years; the dashed lines represent the maximum deficit that is reached in 90% of the years. Potential evaporation is the evaporation in case of optimal water availability.

3.6.6 Gales and surges

The change of the maximum daily wind speed per year of approximately + 2% per degree global temperature rise in the G+ and W+ scenarios, is relatively small compared to the natural year-to-year variation and the long term natural fluctuations. In none of the scenarios, the

currently observed decreasing trend in the number of gales in the Netherlands continues to the same degree.
Storm surges along the Dutch coast are associated with gales coming from western to northern directions. The model calculations used for the four scenarios show only small changes in the gales from these directions.

3.6.7 Wind energy

The observed decrease in wind speed in the past decades in the Netherlands has consequences for the energy production of wind turbines. The maximum energy production of the wind turbines has decreased. The scenarios do not give reason to believe that wind energy production will remain lower in the future. The scenarios with more westerly wind (G+ and W+) seem to indicate a (slight) increase in the long-term. However, for the wind energy sector, the year-to-year variation and long term fluctuations are of much greater importance than the relatively small changes present in the scenarios.

3.7 Conclusions

The climate system is characterised by a large number of processes acting on different temporal and spatial scales. As an additional complication the processes also interact with each other, causing many different feedbacks, both positive and negative. As a consequence the future evolution of (regional) climate is subject to many uncertainties:

- unknown development of anthropogenic activities and related emissions of green house gases and changes in land use;
- limited understanding of the complex climate system: inherent internal variability and its response to changes in concentrations of greenhouse gases and land use chances.

Throughout this chapter various hints were given for directions for future research. Many relevant aspects of the physical mechanism for (regional) climate change are still poorly understood. The following three aspects are of particular relevance for (climate change scenarios for) the Netherlands and Western Europe:

- The circulation response to increased greenhouse gas concentrations. Changes in circulation patterns may have clear effects on temperature increases and precipitation changes in the Netherlands in various seasons. Also the occurrence and strength of gales and surges may be affected;
- The dynamics of glaciers and large ice sheets, and changes in precipitation at high altitudes. These processes affect sea level rise (important for the low lying Netherlands), and may include important positive or negative feedbacks;
- A third group of poorly understood processes that generates strong regional climate variability is the role of land surface.

In general, projected changes have an increasing uncertainty when following the series of variables from temperature via sea level rise, precipitation and wind. Wintertime precipitation is more certain than changes in precipitation in summer. The mean changes are more certain than changes in extremes (events that occur once per 10 year or even less, and also ‘abrupt’ changes). This chain is partly dictated by the complexity of the underlying physical processes.

4 Climate Impacts for the Netherlands: Fresh Water

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4.1 Introduction

This chapter explores the concept of dangerous climate change for the Netherlands, through presenting the latest scientific data on a number of indicators for 'fresh water'. Each section explains an indicator, attempts at categorising acceptable and not acceptable risks, and where possible takes into account the possibility of adaptation. It then concludes with an assessment of the scientific robustness of the different aspects of the assessment.

4.2 Indicators for fresh water

In the area of fresh water, four indicators were seen as important for the Netherlands. These indicators represent sectors, such as navigation, where problems due to climate change will occur. Two indicators are related to river discharge, whereas two are related to precipitation. They are:

- River discharge: climate change affects precipitation and the melting of snow/glaciers, leading to changes in river discharges.
    - Design discharge: This is the discharge that is used to design the dikes, and stands for the safety against flooding.
    - Low river discharge: Low flow situations cause problems for navigation and, in combination with increased temperature, it will affect the availability of cooling water for industry and electricity production.
- Precipitation: Due to climate change the precipitation will change. Comparable with the river discharge this is split into the increase in the winter and decrease in summer.
    - 10-day precipitation sum: This refers to problems due to heavy precipitation in de the regional and urban water system, which is called waterlogging, and which do not pose immediate danger to people.
    - Precipitation deficit: This is an indication for drought, which leads to problems for among others agriculture.

4.2.1 River discharge

The discharges of the Rhine and Meuse rivers are good indicators because they are important for several sectors. They are influenced by climate change and will therefore have impact on these sectors:

- Design discharge is an indicator for the safety against flooding. It is expected that the design discharge will increase with 5 to 10% per degree temperature increase for respectively Rhine and Meuse;
- Low flows: the discharge in the summer is expected to decrease with the following consequences:
    - In combination with increased water temperature the cooling capacity of some power plants will become critical. At the moment there are already problems every 2-5 years;
    - Navigation: The water depth in the river will become lower and also the periods that a limited load can be transported will increase;
    - Water supply to the regional water system will be hindered;
    - Salt water intrusion in the head water system. Problems occur with low Rhine discharge in combination with sea level rise, which causes problems for the intake of drinking water and also the supply of water from the river to the regional water system; and

- It is expected that due to the lower discharge and increase in temperature, water quality problems will increase.

The discharge regime of the Rhine since 1900 shows an apparent trend, which is expected to continue in a more pronounced form in the future. Figure 4.1 below shows monthly average discharges at Lobith, expressed relative to the annual average discharge. During the last few decades in particular there has been an observable shift towards higher average discharges in the winter and lower average discharges in the summer. While there is no direct evidence that this shift is due to climate change, it does fit in with the total picture of climate change. There is also the expectation that the discharge in winter will increase between January until April, and will decrease in summer with a shift of the minimum to September.

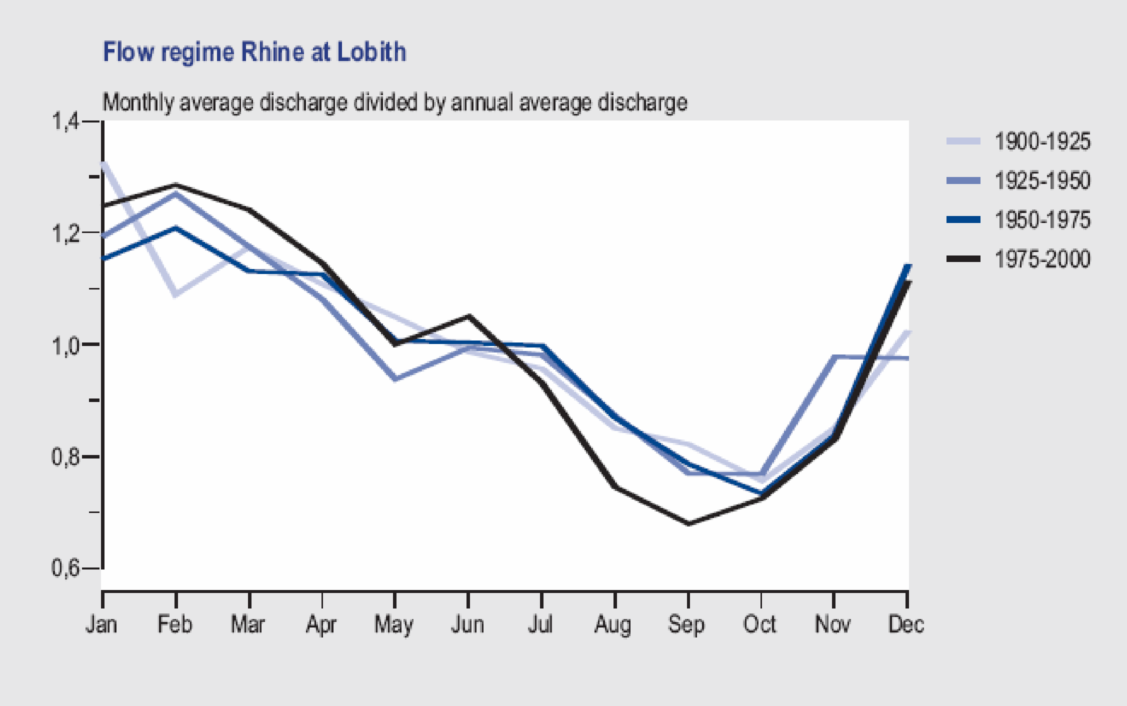

Figure 4.1. In recent decennia the winter discharge from the Rhine has increased and the summer discharge has decreased (Bresser et al., 2005).

Due to climate change, changes will occur in the precipitation pattern in the Rhine basin area. It is expected that the Rhine, at present a combined rain and melt-water river, will increasingly become a rain river with higher discharges in the winter and lower discharges in the summer. The increasing winter precipitation will result in an increase in the discharge of the Rhine in winter. Summer discharge will decrease as a result of a reduced amount of melt water and a strong increase in evaporation, the latter outweighing the effect of the smaller increase in the average rainfall in the summer. (Middelkoop et al., 2000).

Figure 4.2 shows that in all of the climate scenarios the expected winter discharge of the Rhine will increase and the summer discharge will decrease relative to the present discharge. Similar to the expectation for the Rhine, the winter discharge of the Meuse will also be higher in the future than it is at present. For the dry climate scenario in particular, the summer discharge will be even lower. In the present situation a low water level on the Meuse is already a problem, and only a slight change is already enough to make the situation in the summer worse.

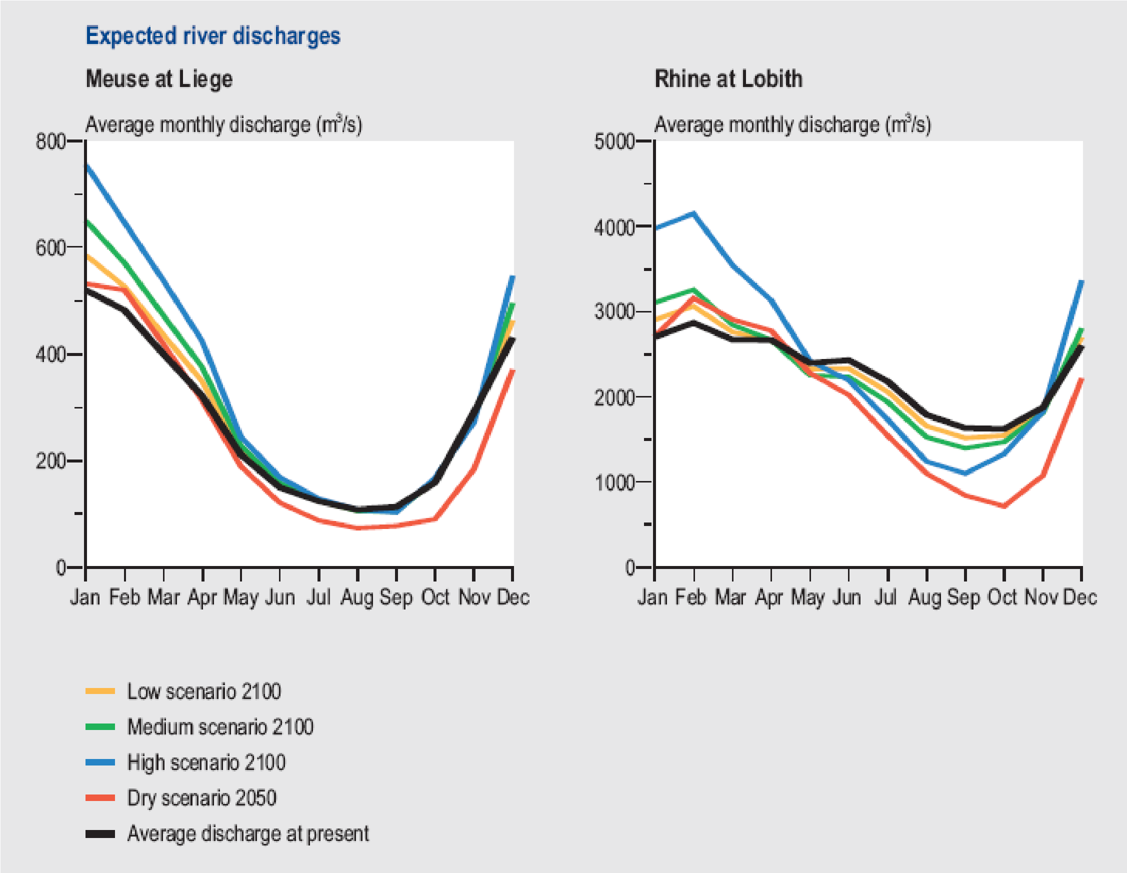

Figure 4.2. In all four of the climate scenarios considered, the winter discharge increases even more in the future; the summer discharge decreases for the Rhine in all of the scenarios and for the Meuse, only in the drought scenario (Beersma et al., 2004).

Navigation

One of the main functions of our water system is transport. It is strongly linked to the discharge of the rivers, which supplies the needed water depth.

In the period up to 2050, the transport costs of inland navigation will mainly change as a result of changes in the supply of freight. According to the 'Drought study' (RIZA, 2005), the expected increase in transport costs as a consequence of climate change will remain limited to between 2 and 4% based on the WB21 middle and high scenario for 2050. In the event of extremely low water levels, such as in 2003, inland ships can only use a fraction of their normal loading capacity, which increases the transport costs considerably. The probability of such low Rhine discharges (monthly mean <1250 m^3/s) and low water levels mainly increases in the dry climate scenario (see Figure 4.3). The negative effects of floating ice on the large rivers will hardly ever re-appear in the future. Partly as a result of climate change, the temperature of the river water is now already much higher than it was several decades ago. It is highly likely that this trend will continue at an increased rate.

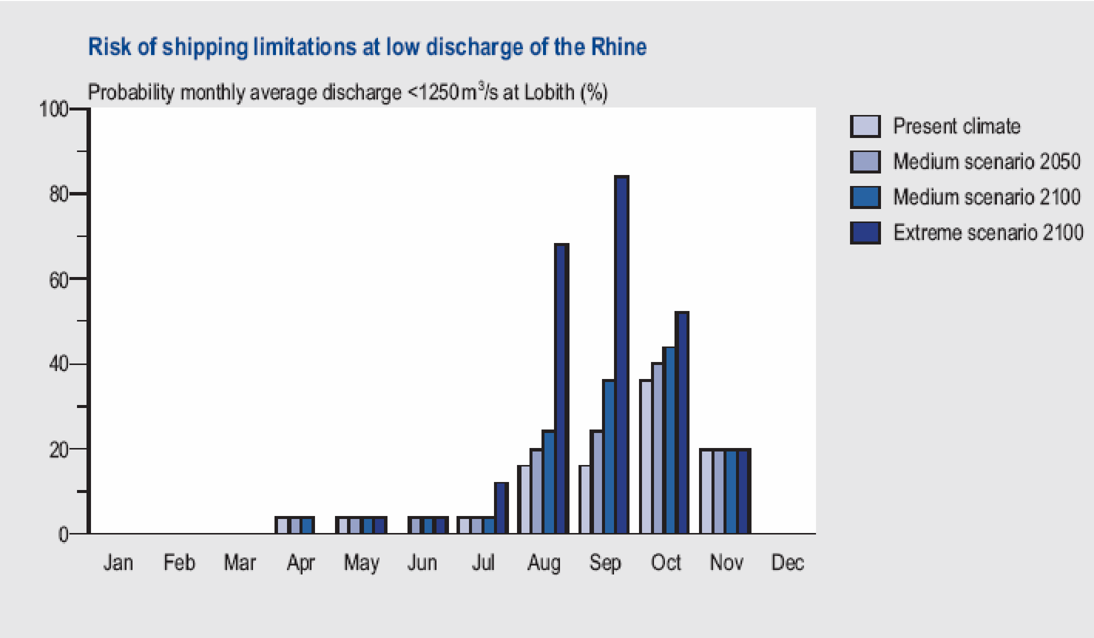

Figure 4.3. The probability of extremely low river discharge and limited navigatable depth mainly increases compared to the current situation (Buiteveld, 2005).

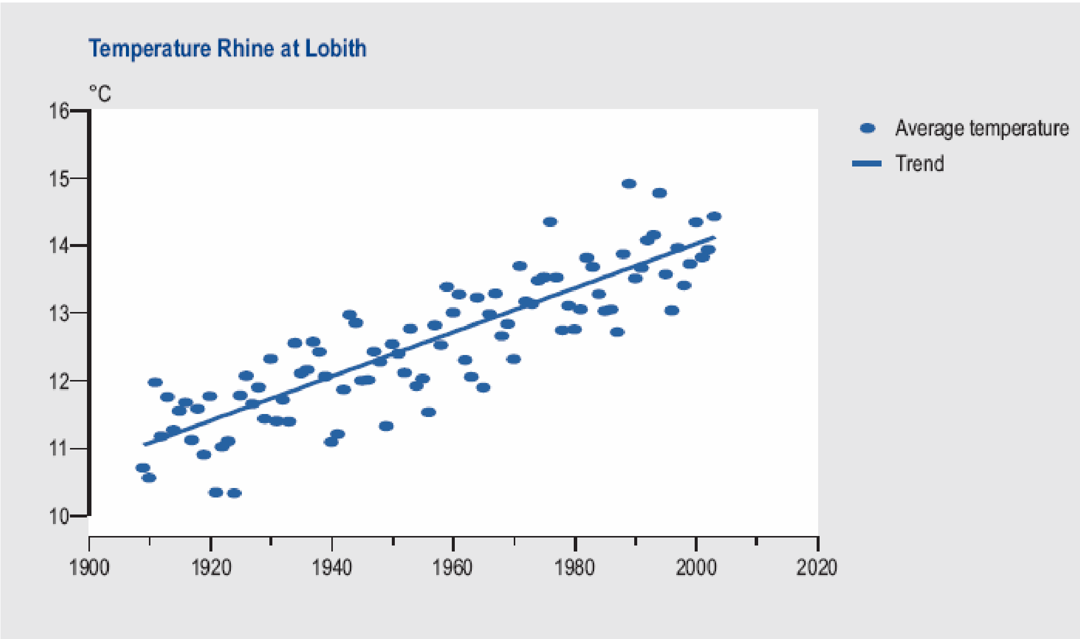

Figure 4.4. Average annual temperatures of the water in the River Rhine at Lobith during the period 1909-2003 (RIZA, 2005).

Cooling water

Surface water is used on a large-scale in the Netherlands as a coolant in the production of electricity, which is of course important for all the other sectors. Two limitations apply to the discharge of cooling water:

- the maximum discharge temperature must be below 30°C;
- the temperature difference between intake and discharge may not be more than 7°C in the summer and 15ºC in the winter.

Consequently, a water temperature of 23°C applies as the critical limit for the use of cooling water.

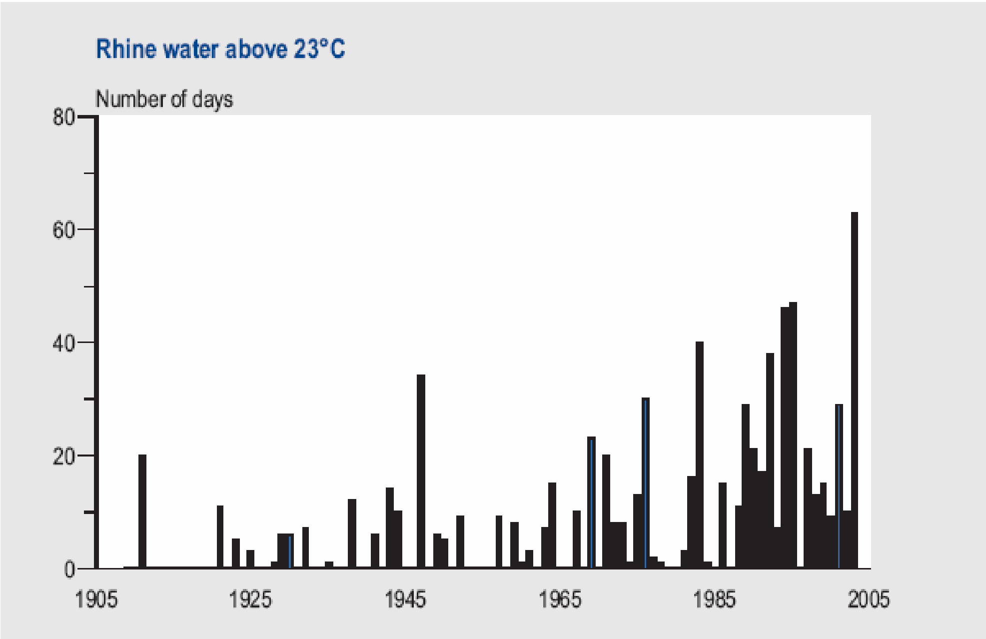

Figure 4.5. Trend in the number of days per year when the temperature of the water in the Rhine was higher tan 23°C during the period 1909-2003 (RIZA, 2005).

Research has revealed that the temperature of the river water is more of a determinant of cooling water restrictions than the discharge of the river (KEMA, 2004). Over the past century the average annual temperature of the water in the Rhine has increased from 11°C in 1910 to above 14°C in 2003 (see Figure 4.4). Two-thirds of this temperature rise is estimated to be due to the increased use of cooling water in Germany and one-third to the increase in temperature as a result of climate change. Due to the temperature rise that has already occurred in recent decennia, the number of days in the year that the water temperature is above 23°C has also increased (see Figure 4.5). During the very warm summers of 1994 and 2003, energy production temporarily decreased as a consequence of a shortage of cooling water; in 2003, a tight situation even arose (code 'red' in terms of the certainty of delivery) for a period of almost 40 days when the water temperature was above 24°C. How the temperature in the Rhine and Meuse will continue to rise in the future is uncertain and depends on both the rise in the air temperature as well as developments in the utilization of cooling water upstream in Germany and Belgium. With a further increase in the air temperature, it can be expected that the water temperature in the Rhine and Meuse will rise and – if the use of cooling water upstream remains the same – the chance of temperatures for which a cooling water restriction applies will also increase. A previous study into the cooling water problem of the Meuse emphasizes that the probability of these problems will increase still further, assuming the current discharge characteristics and use of cooling water. However, the energy sector has various options available for reducing the sensitivity of the system to the temperature of the river water.

4.2.2 Waterlogging

In Dutch water policy a distinction is made between situation which cause danger, such as flooding caused by the river system of from the sea, which can cause casualties and inundations of more than 1-2 m, and situations where flooding has a much smaller inundation depths and causes inconvenience to people and damage to property. Waterlogging is in general caused by heavy precipitation in the regional water system. Examples are the water problems in September and October 1998, which initiated the study 'Water Management 21st Century' (Ministerie van Verkeer en Waterstaat, 2000). This study again resulted in the so-called Drought

Study (RIZA, 2005) and the Dutch National Administrative Agreement on Water[46](Ministerie van Verkeer en Waterstaat, 2003).

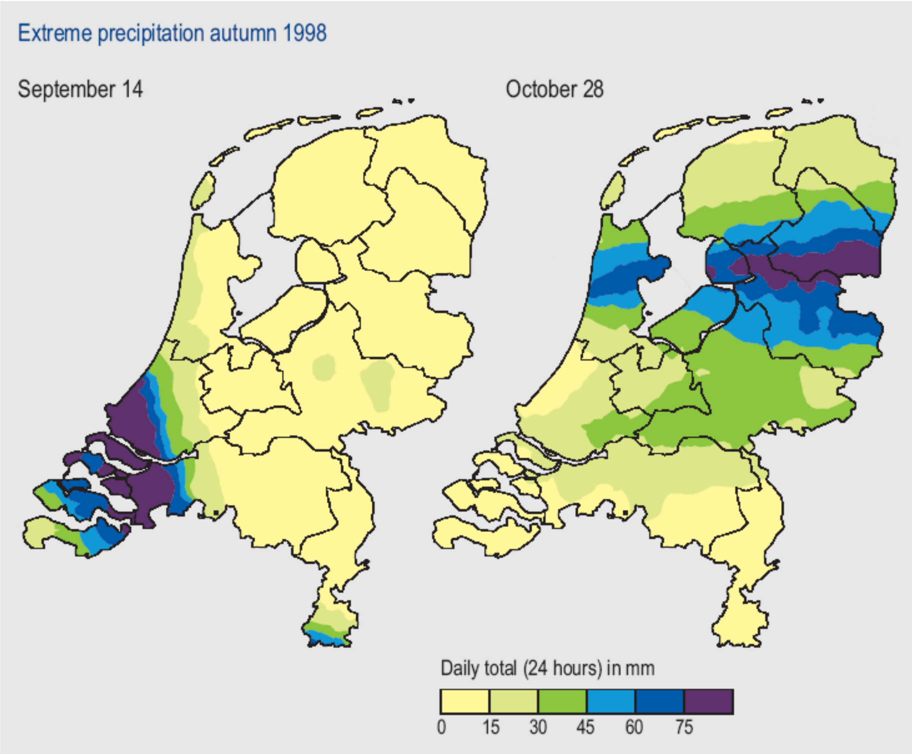

Figure 4.6. Waterlogging problems, during extreme rainfall events, such as the autumn of 1998, different region were affected (after: Rainfall figures KNMI (Bresser et al., 2005)).

In the Dutch National Administrative Agreement on Water, the provinces, municipalities and water boards recognize the expected increase in precipitation and extremes and have jointly compiled working standards to indicate when the term waterlogging can be used for various user functions (see Table 4.1). The agreement made is, that the regional water sytem has to be in order by the year 2015 given climate change (based on the so-called WB21 middle scenario). This agreement is made for two situations: the expected increasing of winter precipitation which causes waterlogging problems and the expected drought problems in the summer situation. In both cases a so-called water assignment is defined.

Table 4.1. Working standards for water logging as agreed in the Dutch National Administrative Agreement on Water.

Standard class related to land use type	Ground level height criterion (%)*	Baseline standard (expressed as 1/estimated number of years)
Grassland	5	1/10
Arable land	1	1/25
High value horticultural and agricultural land	1	1/50
Cultivation under glass	1	1/50
Built-up area	0	1/100

Source: Ministerie van Verkeer en Waterstaat, 2003.

*: The standards are expressed as the probability that the level of surface water will exceed the ground level (probability of inundation by surface water).

46 Dutch National Administrative Agreement on Water - Nationaal Bestuursakkoord Water = Agreement between all the Dutch authorities involved in water management.

For the regional water systems, provinces, municipalities and water boards have made an analysis of the problems in the so-called sub-catchment visions and have assessed the spatial measures necessary to prevent floods. The total amount of land claimed in the sub-catchment visions for solving water problems is about 120,000 hectares for water storage and 430,000 hectares for water retention, based mainly on the assumption of increasing rainfall intensity. However, there are still considerable uncertainties with respect to the measures that will eventually be needed. Most of the sub-catchment visions have adopted a waterlogging standard; i.e. rainfall which occurs once every 100 years. For rural areas the agreed-upon working standards are substantially lower (see Table 4.1). Also in the area of urban drainage problems are expected due to climate change (Luijtelaar et al., 2002).

The increase in precipitation due to climatic change will be visible first in inclined areas Also in systems that are now functioning critically and where problems can currently be absorbed by the temporary storage of water on the street increase of rainfall will result in more flooding.

To reduce future problems, attention should be focused on room for water on the street in urban areas. Uncoupling of rainwater from wastewater systems can be extra effective here. In many situations, rainwater use, infiltration into the ground or discharge into the surface water is an important sustainable option for relieving the load on existing systems.

4.2.3 Rainfall deficit

The Netherlands has a rain deficit (cumulative sum of precipitation minus evaporation) in the summer. This deficit is not experienced as a problem because it occurs every year and agricultural practices take it into account (by means of irrigation or accepting slightly lower production). The surface water system is mostly capable of satisfying the water demand (for the current capacity of irrigation), even in years of extreme drought. Damage to crops arises because the plants are unable to evaporate the quantity of water necessary for optimal growth. This is often a consequence of an insufficient irrigation system capacity or an irrigation ban. A ban on irrigation is a measure, which is often taken to prevent groundwater levels becoming too low in those areas where groundwater is used for irrigation. In the western areas of the Netherlands, the salt concentration of both the surface water and groundwater also imposes a limitation to irrigation.

In the case of a changing climate, the Netherlands will be increasingly confronted with water deficits. In rainfall-dependent areas, especially the more highly situated and drought-sensitive sandy soils, increased precipitation dynamics will also have a negative effect on the production and the quality of the product due to drought damage. The level of damage will partly depend on the irrigation capacity and on possible irrigation bans (if other functions necessitating the ground and surface water have priority). The effects of water deficits are even greater in the dry scenario. In lower parts of the Netherlands, more water will have to be supplied to maintain the water level and to counteract the effects of the land becoming more brackish.

The summer of 2003 was dry and extremely warm. The consumption of drinking water in this year was 2% higher than in 2002. This in itself is particularly striking because drinking water consumption has shown a decreasing trend since 1995. This rise was entirely due to consumers, who used 25 million cubic metres more water (3.5% of the annual consumption by households) than normal, mainly for watering gardens and lawns. The heat wave in June 2005 also led to a record quantity of drinking water being used according to a press release from the Netherlands Water Companies Association (VEWIN). In the week of the heat wave 8 million cubic metres more water was used than the weekly average over the entire year. On the warmest day the use was at times 50% higher than average. The expectation is that the average demand for drinking water will rise by several percentage points due to the rise in temperature. More peaks in the demand for drinking water are expected in the future as a result of climate change. Drinking water reservoirs are being constructed to bridge periods of water shortage due to low river discharges or poor water quality. Lower discharge due to climate change will also affect the water quality; the influence of climate change on the water quality is however not well documented. Water quality also includes accidental spills, which have a great impact in low flow situations. In the lower part of the Rhine and Meuse it will become more difficult to discharge water into the North Sea (Jacobs et al., 2000) due to lower summer discharge in combination with a sea level rise. As a consequence there will be more salt-water intrusion, which threatens the fresh water supply in that area. The salinity of the water taken may not be too high: a critical level equal to 215 mg/kg is presently the upper limit. During periods of very low river flow and high tide, the salinity of the water in the northern part of the estuary may temporarily exceed the critical level for water intake. At the station along the Hollandsche IJssel, water intake becomes limited when the Rhine discharge at Lobith drops below 1200 m^3/s. The question is therefore: are the reservoirs large enough to ensure enough water for drinking water preparation.

4.3 Adaptation options

The Water Management in the 21st Century Advisory Committee recommends the mandatory implementation of the three-step strategy of retaining, storing and draining water. (Ministerie voor Verkeer en Waterstaat, 2000). Additional storage will help to reduce the problems from the increased precipitation. Agreements (Dutch National Administrative Agreement on Water) between the water authorities have been made in order to implement the necessary measures. The project Room for the River is an example for the River Rhine. In the case of river safety the design discharge is used. In the PKB[47] room for the river (Spatial Planning Key Decision Document ‘Room for the River’), additional to the measures to ensure the safety level associated with 16,000 m^3/s, measures for preserving space over the long term have been included to compensate for the future effects of increases in river discharges and the sea level. About 7000 hectares have been reserved along the Rhine. This space will allow for a possible increase in the design discharge of the Rhine of up to 18,000 m^3/s. The actual measures still need to be taken in these reserved areas.

In case of insufficient cooling water for power plants an adaptation option is to move these plants to places where there is enough cooling water with non-critical temperatures, such as now the case for the rivers in warm summers such as 2003.

4.4 Threshold levels

The adaptation of the Dutch water system is done according to the ‘Nationaal Bestuursakkoord Water’, which has to be implemented by 2015. It uses the so-called WB21 climate scenario of +1°C (increase since 1990) for the year 2050. It is expected that during the next decades these figures will be updated, depending on for instance new climate scenarios. For the end of the century, based on the present knowledge, the adaptation is probably according to +2°C. In the case of flooding and waterlogging +2°C (~3°C pre-industrial) is a situation where adaptation is still possible. In the case of low flow, water inlet, cooling water and navigation, however the discharge can become lower than is acceptable, without good possibilities to compensate this.

River discharge: design discharge: In the case of the design discharge of the Rhine at Lobith 18,000 cubic metres per second can be discharged, with the long-term measures foreseen in the PKB Room for the River. Further or more rapid increases would be problematic. Within this context the way the up-stream countries deal and anticipate on the expected climate change is also of influence on the maximum discharge which can reach Lobith.

River discharge: low flow: In the case of low flow there are several sectors which are influenced. For a few sectors an indication of the critical levels is given.

- Navigation: In the present situation the cost increase when the average month discharge of the Rhine is lower than 1250 m^3/s. Below a discharge of 800 m^3/s the water depth in the river

[47] PKB RvR: Planologische kernbeslissing Ruimte voor de Rivier.

will be to low to have enough water depth. In Figure 4.4 it can be seen that there is a strong increase of the discharge lower than 1250 m^3/s between a temperature increase of 2 and 4°C (compared to 1990), the critical level probably lies in between this temperature increase. Adaptation in the Rhine system is difficult, additional weirs will negatively affect the ecological states. Adaptation by the sector is more likely.
- Access to clean water: Discharges lower than 1250 m^3/s will cause problems for the inlet of water because the quality (salt concentration to high) is to bad. This is important for the inlet of drinking water but also for the inlet of river water in to the regional water system.
- Cooling water: Increased temperature with lower flow will cause higher water temperatures. The critical water temperature is 23°. At the moment there are already critical situations, with no adaptation this will increase. There are however various options to reduce the sensitivity of the energy sector to the temperature of the river water. One possibility is to move the locations where there is more cooling water with lower temperature.

Precipitation:
- 10-day precipitation sum: The standard for waterlogging is a rainfall event which happens once in the hundred years. Adaptations are made, based on WB21 climate scenarios for 1 and 2°C increase (~3°C above pre-industrial levels). This also holds for urban-flood management. It is unclear if it is possible to cope with a higher increase.
- Precipitation deficit: The rainfall deficit is an indicator for the regional drought in the Netherlands. The summer of 2003 will occur once every 10 years in the present situation. For the W and G scenario of the KNMI (see Chapter 3) this will be 6-8 years, but under the W+ and G+ this will be 2-4 years. Problems get greater when combined with low flows, which are again a characteristic of the W+ and G+ scenario. In that case the critical level could lie below +3°C (pre-industrial).
-

In the case of cooling water there is in the present situation already a problem. The critical level, however not clearly defined, will therefore be easily passed. The adaptations which will be made in water management to cope with floods and waterlogging will be so that an increase of about +3° (pre-industrial) can be handled. In the case of low flow and drought the critical level could be lower than +3° (pre-industrial) based on the G+ and W+ scenario's.

4.5 Scientific robustness and gaps in knowledge

Based on several studies the expected increase in winter precipitation is believed to be a robust finding. The following expectations for the river discharge and the regional water problems are also robust. However the consequences for the urban drainage system are not yet well-studied. A problem is getting the right input climate change-data. Drought is also a well-studied problem in the Netherlands. However, the scenarios for the summer are more diverse than the expectation for the winter. This gives a higher uncertainty on what can be expected.

5 Ecosystems and Nature Conservation: Determining Dangerous Impacts of Climate Change

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> *"Climate change is already altering ecosystems in such a way that we must ask ourselves about their capacity to adapt. While ecosystems are extremely resilient and typically only change rather slowly, there are growing signs from across the world that they can reach a critical point where they undergo 'greenlash' — or a sudden flip into a new structure."*

Professor Jacqueline McGlade, Executive Director of the European Environment Agency in European Environment Agency (2005).

5.1 Introduction

This chapter provides the motivation for a risk assessment of the threats of ongoing and future climate change on species and ecosystems. The last IPCC impact and adaptation report (McCarthy et al., 2001) clearly stated that not only do we expect large changes in ecosystems in the future due to projected increases in temperature and changes in precipitation but also that we are already observing the impacts of climate change (cf. Box 1).

Box 5.1 Main findings of IPCC's Working group on Impacts and Adaptation (McCarthy et al., 2001).

- Recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems;
- There are preliminary indications that some human systems have been affected by recent increases in floods and droughts;
- Natural systems are vulnerable to climate change, and some will be irreversibly damaged;
- Many human systems are sensitive to climate change, and some are vulnerable;
- Projected changes in climate extremes could have major consequences;
- The potential for large-scale and possibly irreversible impacts poses risks that have yet to be reliably quantified;
- Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts;
- Those with the least resources have the least capacity to adapt and are the most vulnerable.
- Adaptation, sustainable development, and enhancement of equity can be mutually reinforcing.

The IPCC assessment also addressed the threats to species and ecosystems as one of the major 'reasons for concern' in the so-called 'Burning Ember' diagram (Smith et al. 2001), which indicated that above an increase of 2°C in global mean temperature since pre-industrial times, risks to species and ecosystems rapidly increase. This conclusion was later reinforced by the a special IPCC report (Gitay et al., 2002), a report of the Convention on Biodiversity (Ad-Hoc Technical Expert Group on Biological Diversity and Climate Change, 2003) and the Millennium Ecosystem Assessment (Noble et al., 2005; Reid et al., 2005).

Over the last decade many more studies have shown that ecosystems all over the world, are definitely affected by climate change (e.g. Parmesan & Yohe, 2003, Root et al., 2003, Parmesan & Galbraith, 2004, Lovejoy & Hannah, 2005, Root et al., 2005; Both et al., 2006) and that the conclusions of the IPCC assessment seem to be too cautious. Regional and global temperatures continue to increase with the largest increases in the polar regions. Others claim that 2005 was the warmest year on record. Several authors have now argued for lowering this critical threshold in the species and ecosystems 'Reason for Concern' (e.g. Hare, 2003, Leemans & Eickhout, 2004; Hare, 2006, Schellnhuber et al., 2006; van Vliet & Leemans, 2006).

This chapter will review the most recent literature that describes the impacts on species and ecosystems in order to determine critical thresholds of threats to species and ecosystems. We will focus on larger plants, mammals, birds and marine species, and do not specifically address insects and other species groups. Not that these species are not important or not well studied. On the contrary. But due to time constraints and our assumption that the impacts on plants, mammals, birds and marine species are representative for all other species, these species is not discussed. Furthermore, stakeholders probably relate more to changes in the larger and more attractive species.

An initial analysis on ecosystems was done in the NLTCT project for Dutch stakeholders. This analysis resulted in the national Dutch ‘Burning Ember’ figure for the Netherlands (Gupta & van Asselt (eds.), 2004). The major criticism on this figure focused on the (lack of) scientific evidence and motivation behind the indication of each threshold levels. Here we will provide more evidence and additional arguments to allow for a broader acceptance of these critical thresholds of species and ecosystems.

To achieve this we will first provide a update on the impacts of different species and species groups, followed by impacts on ecosystems and biodiversity. The review will focus most strongly on plants and less on other organisms. Plants form the major habitats and form the basis of food chains. Most of the other organisms depend on them. Finally we will synthesis these findings into the species and ecosystem ‘Burning Embers’. We’ll present three different ones: one with a global perspective (as an update of the original figure of the IPCC), one with a more European perspective and, finally, one with a more Dutch perspective. The European focus will complement the European impact Indicators Study (European Environment Agency, 2004), while the Dutch focus will complement the recent reports of MNP (European Environment Agency, 2004; Bresser et al., 2005) but also other recent insights (e.g., Leemans & van Vliet, 2004, Both et al., 2006). All these diagrams will show that climate change will further jeopardize the biodiversity conservation goals currently set by Dutch, European legislation and international conventions.

5.2 Plants and vegetation

Plants are well studied and many changes are observed and analyzed. The main changes linked to climate change involve the phenology (e.g. timing of leaving, flowering and other life-cycle events), physiology (e.g. productivity) and distribution or abundance of individual species. These specific species changes subsequently lead to shifts in the composition of communities and thus in biodiversity.

5.2.1 Changes in phenology

Changes in phenology illustrate the resilience of plants to the inter-annual variability in weather and small changes in climate (Bradshaw & Holzapfel, 2001). Since the early 1970s spring has advanced by at least 16 days in The Netherlands (CBS & MNP, 2004) and by an average of 10 days on the whole northern hemisphere (Myneni et al., 1997). These changes in earlier greening of the biosphere have unequivocally been observed by satellites, first by Myneni et al. (1997). Also other phenological features, such as the release of pollen, are occurring earlier and sometimes over a longer periods (van Vliet et al., 2002). These shifts in plant phenology can trigger many other processes, such as the onset of insect outbursts and pollen allergies.

Observed changes in phenology are nowadays very well documented and occur all over the world (e.g. Sparks & Menzel, 2002; Roy & Asher, 2003, Edwards & Richardson, 2004; Leemans & van Vliet, 2004; Primack et al., 2004; Marra et al., 2005; van Vliet & Leemans, 2006) and are modelled realistically by the regional and global vegetation models (e.g. Lucht et al., 2002). The

Dutch 'Natuurkalender' project[48] systematically collects and reports such changes. Over the last decade, this project identified many local changes (van Vliet & de Groot, 2003; van Vliet, 2004; van Vliet & Bron, 2005) and communicated them through the national radio program "Vara's Vroege Vogels" to a broader public using the slogan 'klimaatverandering in je achtertuin' (i.e. climate change in your backyard). The project has been instrumental in changing the perception of the general public from "climate changes happens some time in the future" to "climate change is happening now". The Natuurkalender has clearly documented that ecological changes are happening faster than expected (van Vliet & Leemans, 2006). However, the data also shows that nature can cope quite well with the onset of climate change (0.7°C warming in the 20th century, c.f. cover figure). The literature does not show large regional differences and it is currently unclear at what levels the phenological coping strategies are inadequate.

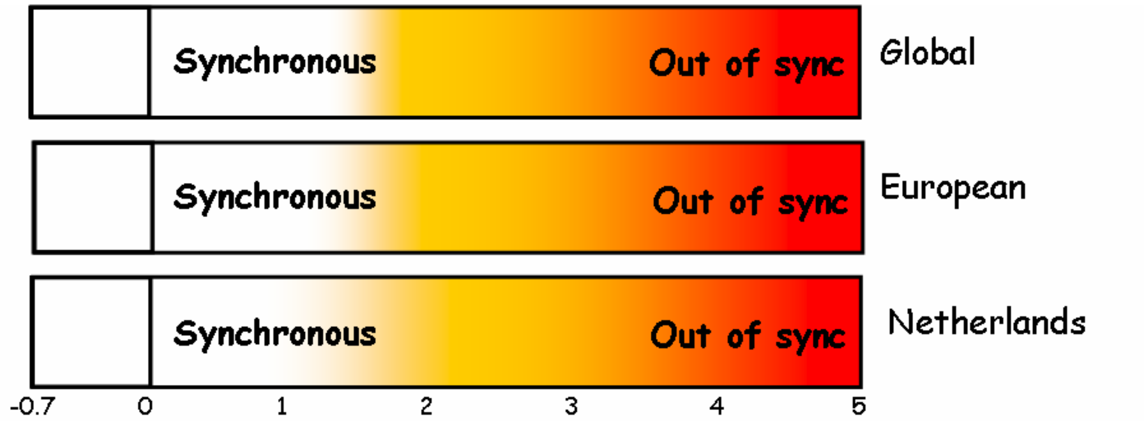

Figure 5.1. The 'Burning Ember' of risks for negative impacts in plant phenology.

5.2.2 Changes in physiology

Physiological changes are different. Many physiological processes (e.g. photosynthesis and respiration) are influenced by temperature levels and moisture availability. Plant species generally increase productivity at higher temperature until a, for each species specific, temperature optimum, after which productivity rapidly declines. Respiration, on the other hand, increases exponentially with increasing temperatures. These relationships for a large part define global and regional productivity and carbon sequestration patterns. (e.g. Valentini 2000, King et al. 2006, Reich et al. 2006). A decade ago, some studies already indicated that the world's ecosystems, which currently sequester approximately 25% of the anthropogenic CO_2 emissions, could shift and become a CO_2 source (Betts et al., 1997; Woodward et al., 1998; Cramer et al., 2001). These results were, however, strongly dependent on the model and climate change scenario used. Recently, this possibility has been determined more systematically with series of scenarios and models. The ATEAM project (Schröter et al., 2005), for example, used all the IPCC SRES emission scenarios and 4 different GCM-based climate scenarios and showed that in the second half of this century, Europe's ecosystems would shift from a sink to a source. Scholze et al. (2006) even took a more rigorous approach using the IPCC SRES scenarios combined with 18 different climate scenarios ranging from a low to high climate sensitivity. They indicated high risks of forest loss for Eurasia, eastern China, Canada, Central America and Amazonia, with forest extensions into the Arctic and semi-arid savannas. In most scenarios this loss creates a considerable net carbon source from the biosphere. At global mean temperature increases of more than 3°C compared to current climate, the global biosphere converts to a carbon source during the 21st century in approximately half of the scenarios. At around 2°C the fraction drops to 15% and remains about 5-10% at even lower temperature. These are large

48 See www.natuurkalender.nl.

risks. When such a likely shift occurs, the effectiveness of mitigation measures[49] will be strongly decreased and achieving the stabilization objective of the UNFCCC is jeopardized. With these more robust studies, the risks can now more precisely be specified in a 'Burning Ember' (see Figure 5.2 below).

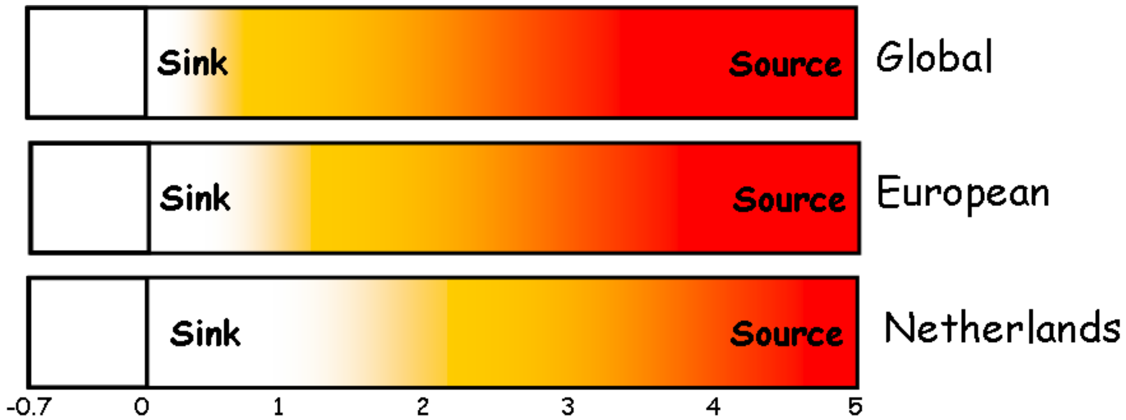

Figure 5.2. The 'Burning Ember' for vegetation productivity. Assessed is the risk that the current carbon sink function turns into a carbon source under changed climate conditions.

5.2.3 Changes in distribution

Each plant species has a characteristic distribution, partly due to their specific physiological limits, but also because of historical reasons and their ability to spread (migrate) through propagules. Distributional limits are further determined by extreme weather events. For example, some species tolerate frost or drought better than others. Trees die when temperature drops once in a decade below -40°C. This rare threshold determines the tree limits in mountainous or polar areas.

It is generally believed that at the beginning of the 20th century continental and global vegetation patterns were in equilibrium with climate. This is now changing rapidly (McCarthy et al., 2001). Many model studies show large shifts in vegetation for each degree of warming (Woodward, 1987; Leemans et al., 1996; Neilson and Drapek, 1998; Malcolm et al., 2002; Leemans & Eickhout, 2004). The so-called biome models indicated the potential magnitude of the change but did not show the individual species response and the real consequences for vegetation composition and thus biodiversity.

Recent research shows that these impacts are more severe than earlier imagined. One of the first species oriented studies was conducted by Thomas et al. (2004). They used differed approaches and scenarios to determine extinction risks. They predict for 2050 that 15-37% of species could be 'committed to extinction'. The conclusion of this study, however, remains controversial because of the use of too simple approaches and scenarios. Another more decent study by Thuiller et al. (2005) used species-specific models and linked those to changes in European biodiversity. They projected late 21st century distributions for 1,350 European plants species under seven climate change scenarios and applied IUCN's Red List criteria to these changes. The study shows that many European plant species could become severely threatened: more than half of the species studied could be vulnerable or threatened by 2080. Expected species loss and turnover proved to be highly variable across scenarios and across

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49 In order to stabilize atmospheric greenhouse gas concentrations (the objective of UNFCCC), emissions should equal the uptake by oceans and the biosphere. If the biosphere shifts from a sink (currently c. 1.5 Gt C) to a source anthropogenic emissions have to be further reduced by at least 1.5 Gt C plus the size of the source. Current anthropogenic emissions are approximately 6 Gt C.

regions. Modelled species loss and turnover were found to depend strongly on the degree of change in just two climate variables describing temperature and moisture conditions. Despite the coarse scale of the analysis, species from mountains could be seen to be disproportionably sensitive to climate change. The boreal region was projected to lose few species, although gaining many others from immigration. The greatest changes are expected in the transition between the Mediterranean and Euro-Siberian regions. They concluded that risks of extinction for European plants might be large, even in moderate scenarios of climate change.

There are many indirect impacts of climate change. Increased drought could increase fire risk (Schröter et al., 2005). Pests could also emerge, such as the emergence and northwards spread of the oak processionary caterpillar (*Thaumetopoea processionea*). After its first observation in 1991 in the southern part of the Netherlands, this species advanced its distribution range to the mid-Netherlands. The species requires warm conditions and originates in southern and central Europe. The caterpillars are a concern to human health as each caterpillar has up to 700,000 stinging hairs that can cause skin rashes (Moraal et al., 2003).

That insects have the ability to quickly respond to changes in climate is illustrated by the enormous northward expansion of the Mountain pine beetle (*Dendroctonus ponderosae*) in Canada in the latter half of the 20th century. The expansion is caused by a series of mild winters that did not kill the beetles. Logan and Bentz (1999) have projected that the species will expand its distribution in response to increases in temperature. Data from the Canadian Forestry Center show a significant increase in the number of infestations occurring in areas that were historically climatically unsuitable for the beetle. The mountain pine beetle population has doubled yearly in the last several years. It caused mortality of pine trees across about two million hectares of forest in British Colombia in 2002 alone. The beetle's range has been limited mainly to the southern half of British Colombia by the occurrence of cold winter temperatures and summers too cool for the beetles to complete their development in a single year (Anonymous, 2003). These large-scale pest infestations have large economic impacts on the forestry sector. Also in other places pest infestations have strongly increased (see Figure 5.3).

Is the impact of climate change in the Netherlands on species distributions already apparent? Within Europe, the ecosystems and landscape of the Netherlands are unique and diverse. Especially the dunes, coastal wetlands and wet and dry meadows rank among the most precious habitats of Europe. Many boreal (i.e. northern) species have their southern border here, many continental species their western border, many Mediterranean their northern border, while a lot a maritime species are in the mid of their range. Lichen species, which are carefully monitored because of their sensitivity for air pollution, showed the first response. Over the last decades their abundances increased again but simultaneously many new Mediterranean and even a few tropical species appeared into the Dutch flora (van Herk et al., 2002; van Herk & Siebel, 2003). Lichens have very light spores as propagules that can easily travel large distances. Available habitats will therefore be rapidly colonized. The increase in southern species has not yet corresponded with a simultaneous decline in northern species.

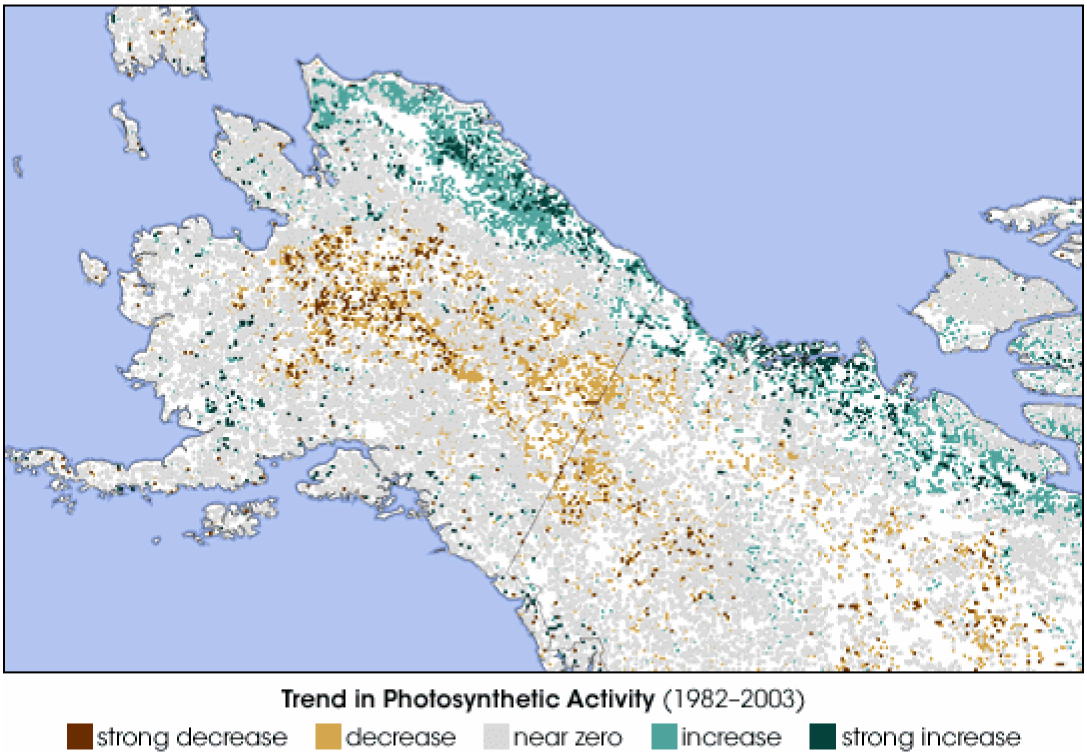

Figure 5.3 Satellite derived change in forest productivity in Alaska and Northern Canada. The brown colors indicate increased pest occurrences (Source: NASA).

Will Tamis and his colleagues (Tamis, 2005; Tamis et al., 2005a; 2005b) analysed an extensive database of the Dutch flora in the 20th century on a scale of approximately 1 km^2. They empirically analysed and established the cause of the major different trends. In the first half of the century, land-use change was the major driver. This continued in the fifties and sixties but combined with an increase of agricultural intensification with a reduction in traditional diverse landscapes (increased fragmentation). The seventies and eighties are marked by a strong domination of shifts in plant composition due to eutrophication (fertilizer and N-deposition). The combined effect of agricultural intensification and eutrophication was definitely the most important driver of change during the 20th century. This is illustrated by the strong overall decline in oligotrophic species (i.e. adapted to nutrient-poor conditions) and a marked increase in eutrophic plant species. Until the eighties, there were small but significant increases in the presence of both warmth and cold-loving plants. However, in the last decades there was a marked increase in warmth-loving species only. Urban areas, which also expanded over this period, were examined as a possible explanation for the increase in warmth-loving plant species but were found to explain only part of it. The changes in the last decades significantly coincided with the marked increase in observed temperatures, evidence at least of a rapid response of Dutch flora to climate change. Up till now the Dutch flora has been enriched by southern species (i.e. more species diversity) but these species are the opportunistic trivial species that occur in many places. The rarer, more specialized species have declined in abundance. These species are less resilient to change, especially because their regeneration is slow. This could well mean that the extinction of these species are already triggered. They only just hang in.

All these studies show that climate change is a serious driver of change in species distribution and abundance and an additional major treat to biodiversity (besides habitat destruction, fragmentation, alien species, pollution and exploitation). Malcolm et al. (2006) have assessed the magnitude of this threat at the global scale. They used major vegetation types (biomes) as proxies for natural habitats and, based on projected future biome distributions under changed climates, calculated changes in habitat areas and associated extinctions of endemic plant and vertebrate species in biodiversity hotspots. Like most more recent studies they looked at a series of scenarios and different factors, including average migration rates. Projected percent extinctions ranged from <1 to 43% of endemic species (average 11.6%). Especially vulnerable hotspots were the Cape Floristic Region, Caribbean, Indo-Burma, Mediterranean Basin, southwest Australia, and the tropical Andes, where plant extinctions per hotspot sometimes exceeded 2000 species. Under the assumption that projected habitat changes were attained in 100 years, estimated global-warming-induced rates of species extinctions in tropical hotspots then exceeded those due to deforestation. This rapidly emerging threat to biodiversity is also identified by the UN Convention on Biological Diversity in its second Biodiversity Outlook (Secretariat of the Convention on Biological Diversity, 2006; ten Brink et al., 2006). They clearly state that a global mean temperature of more than 2°C is unacceptable.

Also the Millennium Ecosystems Assessment (Carpenter et al., 2005; Reid et al., 2005) projects on the basis of both an analysis of current trends and by exploring scenarios of plausible futures that biodiversity loss, and in particular the loss of species diversity and transformation of habitats, is likely to continue for the foreseeable future. This is largely due to inertia in ecological and human systems and to the fact that most of the direct drivers of biodiversity loss—habitat change, climate change, the introduction of invasive alien species, overexploitation and nutrient loading—are projected to either remain constant or to increase in the near future.

Globally, climate change strongly affects species, ecosystems and biodiversity and lead to an overall decline in biodiversity. This has also been observed in the past. Biodiversity declined especially in periods with rapid climate change (e.g., due to the younger Dryas of 12,000 years ago). Besides a absolute maximum for the global mean temperature increase, ecologists have always stated the importance of limiting the rate of change (Vellinga & Swart, 1991; Root et al., 2003). There are many indications that to allow natural ecosystems to adapt naturally to climate change, this rate should definitely not exceed 0.1°C per decade for long (Swart et al., 1998; van Vliet & Leemans, 2006). This corresponds to maximally an additional 1°C during this century. The current rate is 0.3°C per decade. Risk in the 'Burning Ember' for global ecosystems will therefore increase rapidly beyond 1°C. Despite the likely lag in response, the current evidence shows that the ecosystems and species in the Netherlands are a little more resilient, indicating somewhat lower risks (See Figure below).

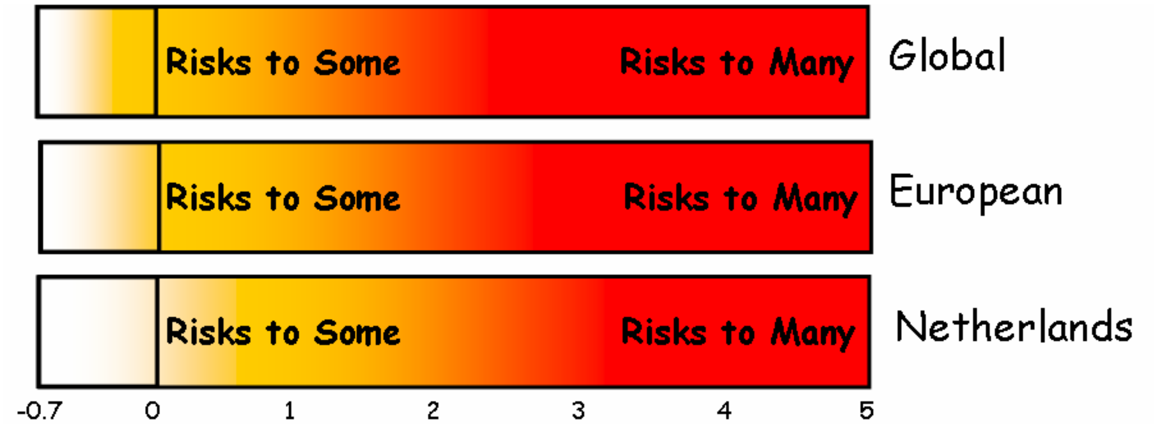

Figure 5.4. The 'Burning Ember' for risks of negative impacts of plant species and vegetation shifts and the subsequent consequences for biodiversity.

5.3 Mammals

Climate change and land use change are threatening wildlife globally (McCarthy et al. 2001; Hassan et al., 2005, Secretariat of the Convention on Biological Diversity, 2006). Land use change decreases and fragments their habitats. Larger mammals often have a position at the top of the food chain. Therefore, they are very vulnerable to changes in the levels below them. They are also sensitive to a large number of indirect impacts of climate change.

For example, Polar bears (*Ursus maritimus*) live throughout the ice-covered waters of the Arctic. However, these preferred sea-ice habitats are now changing rapidly (Arctic Climate Impact

Assessment, 2004). The changes in sea-ice will lead to shifts in trophic interactions involving polar bears through reduced availability and abundance of seals, which is their main prey. A cascade of impacts beginning with reduced sea ice will be manifested in reduced build-up of fat tissue. This could lower reproductive rates because females will have less fat to invest in cubs during the winter fast. As sea ice thins, and becomes more fractured and labile, it is likely to move more in response to winds and currents so that polar bears will need to walk or swim more and thus use greater amounts of energy to maintain contact with the remaining preferred habitats.

The effects of climate change are likely to show large geographic, temporal and even individual differences and be highly variable. All polar bears show some adaptive behaviour but given the rapid pace of ecological change in the Arctic, the long generation time, and the highly specialized nature of polar bears, it is unlikely that polar bears will survive as a species if the sea ice disappears (Arctic Climate Impact Assessment, 2004). The habitat of the polar bears will likely disappear with 1-2°C in global warming. Climate change will soon be a severe threat to these animals.

Thuiller et al. (2006) assessed the sensitivity of 277 mammals at African scale at 10' resolution. The relationships between species' current distribution and macroclimatic variables are established with generalized models. Future projections are derived using different scenarios up to 3°C to estimate the spatial patterns of loss and gain in species richness that might ultimately result. They then applied the IUCN Red List criteria of potential range loss to evaluate species sensitivity and estimated the sensitivity of 141 national parks in terms of both species richness and turnover. Assuming no spread of species, 10–15% of the species are projected to fall within the critically endangered or extinct categories by the middle and between 25% and 40% by the end of this century (10–20% with unlimited species spread). Spatial patterns of richness loss and gain show contrasting latitudinal patterns with a westward range shift of species around the species-rich equatorial zone in central Africa, and an eastward shift in southern Africa, mainly because of latitudinal aridity gradients across these ecological transition zones. National parks in dry shrub land face significant species losses. Other national parks might expect substantial losses but also influxes of species. On balance, the national parks might ultimately realize a substantial shift in the mammalian species composition of a magnitude unprecedented in recent geological time. They conclude that the effects of climate change on wildlife communities may be most noticeable as a fundamental change in community composition. Such a change will have large impacts on, for example, the tourist sector.

In their study, Thuiller et al. (2006) did not consider the direct effects of CO_2 on the species composition of grasses. Currently most palatable grasses, on which wildlife depends, consist of so-called C4-grasses, well adapted to low atmospheric CO_2 concentrations and dry conditions. Increasing CO_2 concentrations will favour so-called C3 grasses. These grasses take advantage of higher CO_2 concentrations by growing faster and improving their water and nutrient use efficiency. Unfortunately, such grasses are much less palatable. Such a shift will also affect wildlife (Walker, 2001).

Studies from Europe show that especially the northern mammals, such as reindeer and moose, are sensitive. A slight warming leads to increase ice snow conditions that limits access to food in winter times and this has negative consequences for their fitness and survival (Weladji & Holand, 2003). No specific climate change impacts studies are done for mammals in the Netherlands. It is therefore difficult to state their sensitivity and vulnerability. Only a general global and European 'Burning Ember' can therefore only be developed for mammals. The studies indicate that the risks really start to increase rapidly beyond 1-2°C.

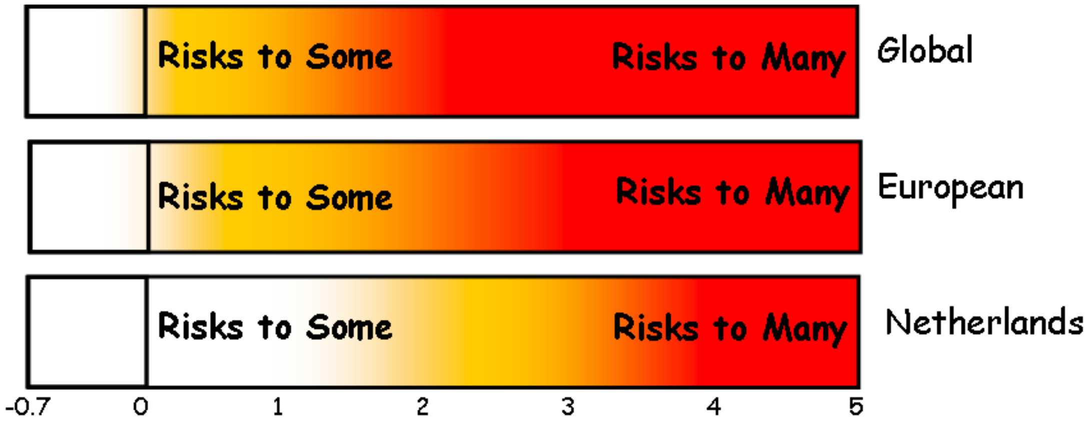

Figure 5.5. The 'Burning Ember' for risks of negative impacts on mammal species.

5.4 Birds

More is known about birds' response to climate change than for any other animal group, mostly as a result of many species- or location-specific analyses. However, compared to other species, there are comparatively few global or international studies in this area. Climate change is affecting birds' behaviour, distributions and populations, and has already caused complete breeding failure in some populations.

There is compelling evidence that, with 0.7°C of warming having already occurred, strong negative impacts on birds are clearly being detected.

The majority of evidence indicates that the projected climate change will have very serious effects, including huge shifts in bird distributions, major population declines and unprecedented levels of extinction. For migratory birds, climate change poses a greater threat to survival than all other threats combined (Robinson et al., 2005).

Highly sensitive to climate and weather, birds are pioneer indicators of climate change, the quintessential "canaries in the coal mine." As global warming brings changes in temperature, altered moisture and precipitation, more extreme weather and a generally more variable climate, birds from the Arctic to Antarctic are already responding (Parmesan & Galbraith, 2004, Root et al., 2005).

In the future, climate change will also affect birds indirectly through sea level rise, changes in fire regimes, vegetation changes and land use change. Climate change could eventually destroy or fundamentally change 35% of the world's existing terrestrial habitats. In the Arctic, where several hundred million migratory birds breed, warming of two to three times the global average is predicted to destroy more than 90% of some bird species' habitat at higher levels of warming. In Europe, Mediterranean coastal wetlands, critical habitat for migratory birds, could be completely destroyed by 2080 (Gitay et al., 2002).

Climate change will also wreak some of its most serious but least predictable impacts by shifting the timing of natural events, and by shifting species' geographical distributions. This will re-arrange plant and animal communities and ecosystems, and disrupt birds' relationships with predators, competitors, prey and parasites. These changes are expected to alter the makeup and functions of most, if not all, of the world's ecosystems (Lovejoy & Hannah, 2005). Evidence suggests that many bird species will not be able to adapt.

5.4.1 Shifts in timing

The early warning signs of climate change can be seen in shifts of the timing of important seasonal events for birds such as egg laying and migration. Some birds in Europe have even stopped migrating altogether with climate warming. These timing shifts are a threat when they force birds out of synchrony with plants and insects upon which they depend. British migratory birds, for example, have typically advanced these spring behaviours by two days per 1°C of warming, but plants have typically advanced much more, six days per 1°C (Robinson et al., 2005).

In Europe populations of Pied flycatchers, long distance migratory birds, have already suffered a 15% decline in breeding success because they arrive in Mediterranean breeding grounds too late, with peak food supply having occurred too long before peak demands of nestlings (Both & Visser, 2001) and now there is also strong evidence for large population declines (Both et al., 2006). Thus these climatically-forced shifts can harm birds' reproductive success and survival, and could even contribute to the collapse of breeding populations over the long term. The mismatch puts serious additional pressure on long-distance migrants, a major iconic bird group already in rapid decline in Europe from a variety of threats.

5.4.2 Range shifts

There is powerful evidence that birds, along with other animals and plants, are already shifting their ranges because of climate change. Importantly, research indicates that although range changes will vary for different species, range contractions are expected to be more frequent than range expansions (Böhning-Gaese & Lemoine, 2004). Both the direct and indirect effects of these range shifts pose major threats to birds. In the northern hemisphere, bird species are already shifting their northern boundaries pole-ward, while at the tropics some birds are shifting to higher altitudes on mountains.

Future range shifts and contractions will occur as vast areas of bird habitat are lost or altered due to climate change, with bird population declines or extinctions an inevitable outcome. In North America, approximately 2°C of warming will reduce the world's most productive waterfowl habitat by half (Sorenson et al., 1998), also halving this zone's duck numbers. Global warming of 3-4°C would eliminate 85% of all the world's remaining wetlands, critical habitat for migratory birds (Secretariat of the Convention on Biological Diversity, 2006). Looking at examples of the threat to individual species, the Spanish imperial eagle and Marmora's warbler (both found only in Europe) will entirely lose their current range under future warming scenarios, putting them at high risk of extinction.

The rate of climate change also poses a major threat. Human-induced climate change will cause rates of change that are historically unprecedented, with species forced to shift at a rate ten times faster than during any climatic change seen at least since the last ice age. This will exceed the ability of many plants and animals to migrate or adapt.

As birds' climate space shifts with global warming, many species may be unable to shift with it because their habitat is already fragmented and disconnected from potential new, climatically suitable areas. Physical barriers such as mountains, large bodies of water and human development present further obstacles to migration. This has conservationists extremely concerned, because many centres of species richness for birds are now in protected areas -- from which they will be forced by climatic changes into unprotected zones and an uncertain future (Lemoine & Bohning-Gaese, 2003).

Also of great concern is the threat that range shifts caused by climate change will easily disrupt, or as some scientists describe it, "tear apart" communities of birds and other interdependent plants and animals. This will occur because birds, and key species they interact with, are unlikely to shift as intact communities. Birds will be brought together with different prey species, parasites, predators and competitors, as their habitats change or they are forced into areas less ideally suited to them. Illustrating the magnitude of this threat, 80% of the chicks of the yellow-eyed penguin (the world's rarest penguin) died from avian diphtheria in 2004 as virus-carrying pests proliferated in wetter springs and summers, a trend linked to climate change. Shifts in prey species have also profoundly affected birds' breeding success. In the North Sea climate change has been linked to extreme declines in sand eel (a small fish) populations in key areas, to a hundredth or a thousandth former levels, causing complete breeding failure in some seabird colonies that rely on these fish for food (Robinson et al., 2005). Thus shifts that re-organize natural communities are expected to produce further, still stronger, changes as bird populations respond to new levels of disease, prey and predation (Pounds et al., 2006). Most analyses to date have not yet considered these secondary impacts, and future research that does is likely to greatly increase estimates of risk to birds of climate change.

5.4.3 The scale of climate change impacts

Climate change will thus have serious negative consequences for many bird populations (Saether et al., 2004) and has already been linked to population declines and drastic reproductive declines (Both et al., 2006). Looking to the future, the worst of possible impacts -- extinctions of entire bird species -- are predicted. Numerous studies link climate change to declines in population and breeding success in birds around the globe. For some groups, the effects are drastic. During an unprecedented 2004 breeding crash in North Sea seabird colonies, some bird populations completely failed to produce any young and some starving birds resorted to eating their young. As noted above, the crash was linked to warming ocean waters associated with climate change, which caused the birds' prey species to shift up to 1,000 km away (Thompson & Ollason, 2001; Frederiksen et al., 2004). An analogous 2005 breeding crash of seabird populations on North America's west coast is also being investigated.

Like seabirds, island birds are also highly vulnerable to climate change. Endangered Galapagos penguin populations have halved since the 1970s because the adult penguins become emaciated (sometimes dying) and fail to reproduce during severe El Niño years. Because climate models predict El Niño to become more frequent in future (Timmerman et al. 1999), it is entirely plausible the penguins along with several dozen other species of endemic Galapagos island birds will vanish within decades.

Birds are also responding strongly to the more pronounced and frequent extreme weather events that accompany global warming in certain regions. The 97% breeding decline of California arid-land birds during a record 2002 drought potently illustrates the highly destructive and disproportionate effect of climate extremes on birds (Bolger et al., 2005).

Climate change puts many bird species at risk of extinction, even those currently considered safe; the stronger the climate change the stronger the risk. Among particularly vulnerable groups – migratory, Arctic, Antarctic, island, wetland, mountain and seabirds – the forecast impacts are severe. The threat of climate change to migratory birds is equal to the sum of all other human-caused threats combined (Robinson et al. 2005) with a full 84% of migratory bird species[50] facing some type of climate change threat.

The overall extinction risk of climate change to birds is still being quantified (Table 5.1; Thomas et al., 2004). However, initial research presents the prospect of extinction of more than a third of all European bird species due to climate change if the species cannot shift to new ranges. Candidates for extinction up to 2050 in Europe include the red kite (expected to lose up to 86% of its habitat) and the Scottish crossbill (expected to lose 100% of its current habitat). The situation is worse still in the Australia Wet Tropics Bioregion, where climate change could force the extinction of almost three quarters (72%) of bird species.

[50] Those birds listed with the Convention on the Conservation of Migratory Species (CMS)

Table 5.1. Predicted bird extinctions for different scenarios up to 3°C.

Region	Predicted bird species extinctions		Warming Scenario	Current # of bird species
	With Dispersal	No dispersal		
Europe	4-6%	13-38%	> 2 °C	526
South Africa	28-32%	33-40%	1.8 – 2.0 °C	951
Australian Wet Tropics	49-72%	N/A	> 2 °C	740
Mexico	3-4%	5-8%	1.8 – 2.0 °C	1060

Source: Thomas et al. 2004.

However, many of the current extinction projections for birds, despite being very high for some regions, could be underestimated (Leemans & van Vliet, 2004). Most research considers only the direct impacts of climate on shifting or contracting ranges. Very few studies capture indirect effects such as radical changes to communities, for example, the increased disease incidence or drastically reduced prey availability discussed above. Many analyses also consider only a limited number of climate variables, potentially underestimating risks of key climatic changes (Pounds & Puschendorf, 2004). Furthermore, most analyses have not yet factored in the devastating impact of climate extremes, which will exacerbate threats (Parmesan et al., 2000; van Vliet & Leemans 2006).

In fact, the expected combination of climate change and other human disturbances such as habitat loss has been termed an "extinction spasm" due to the potential to disrupt communities and wipe out entire populations (Root et al. 2003, Root et al. 2005).

In this review, the significant and in some cases highly destructive impacts of climate change on birds are shown, as well as projections for the future which predict major collapse of some bird populations, and extremely high rates of extinctions in some zones. Indications are that further research will upgrade the climate change risk of extinction to birds, as the range of impacts is more fully considered. Given that climate change is expected to shift important, species-rich bird communities out of protected areas, further research is crucial. If conservation efforts are to cope with climate change, a fundamental change in the approach to bird conservation will be needed for bird species diversity to be maintained. The review clearly shows that the irreversible impacts on bird species seem to evolve more rapidly and are more irreversibly. This means that the 'Burning Ember's are tighter than for plants. To protect the migratory bird communities, global mean temperature increase should be maximally 1°C. This level is based on the already existing evidence of observed negative impacts for many species. Non-migratory bird species are probably less sensitive and vulnerable. Here a maximum level of 1.5-2.5°C is recommended.

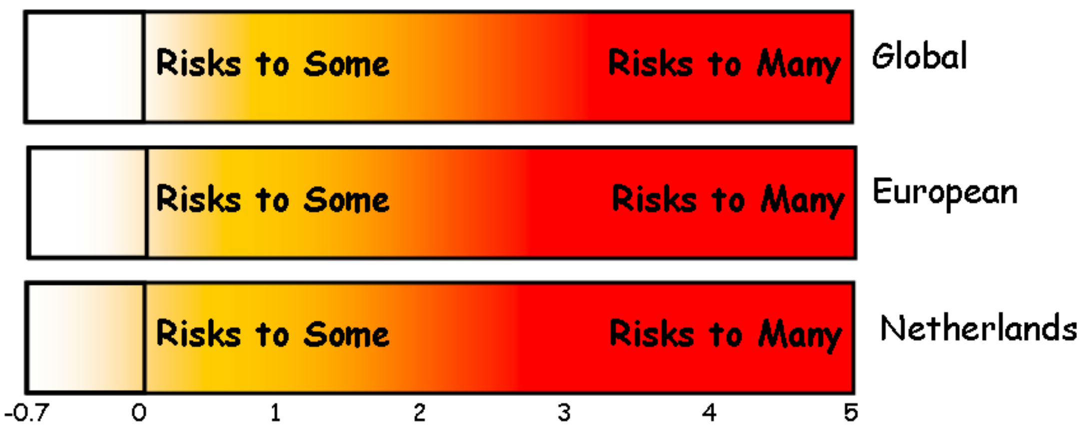

Figure 5.6. The 'Burning Ember' for risks of negative impacts on non-migratory bird species.

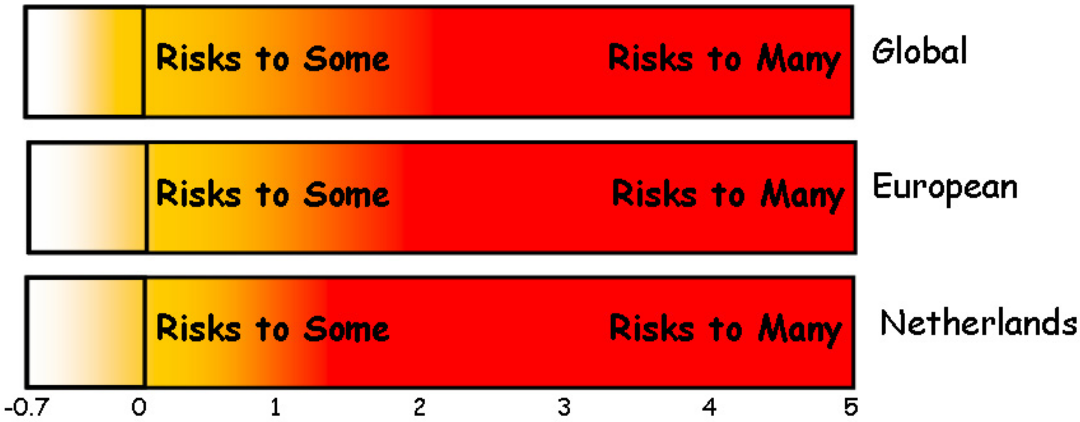

Figure 5.7. The 'Burning Ember' for risks of negative impacts on migratory bird species.

5.5 Marine species

In the climate change indicator report of the European Environmental Agency (European Environment Agency, 2004) phytoplankton biomass was presented as an indicator for the marine growing season. The biomass has increased considerably over the past few decades in parts of the northeast Atlantic and the North Sea. In the late 1940s to the 1980s, the majority of production was restricted to bloom periods in spring and autumn. However, production has significantly increased during the winter and, especially, the summer season since the late 1980s. Particularly high increases have been observed since the mid-1980s in the North Sea and west of Ireland between 52°N and 58°N. During the 1990s phytoplankton biomass increased in winter months by 97% compared with the long-term mean. Changes in annual phytoplankton biomass and the extension of the seasonal growing period already appear to have considerable impacts on overall biological production and the food web. Change in the seasonal timing of decapod larvae (as an example for zooplankton) over the period 1948–2000 shows a similar behaviour. Although there is considerable inter-annual variability of decapod larvae in the period 1948–2000, since 1988 the seasonal development of the larvae has occurred much earlier than the long-term average. The seasonal cycle was up to 4–5 weeks earlier in the 1990s than the long-term mean (European Environment Agency, 2004).

Reptiles also have changed in the timing of their life cycle in response to temperature. Weishampel et al. (2004) examined 15 years of Loggerhead sea turtle (*Caretta caretta*), nesting patterns on the Atlantic coast of Florida, which is among the most important nesting area for this threatened species. The nesting date became earlier by roughly 10 days. This was significantly correlated with near-shore, May sea surface temperatures that warmed an average of 0.8°C over this period.

Sea turtles display strong sensitivity to climate change. Hays et al. (2003) reconstructed nest temperatures of a major green turtle (*Chelonia mydas*) at Ascension Island since 1855. The temperature of the sand varied around 3 °C between different beaches. This variation has persisted for at least a century. Reconstructed nest temperatures varied, however, by only 0.5°C over the course of the nesting season but differed for the individual beaches. Nest temperature strongly determines the sex: the coldest sites produced male offspring, while the warmer site produce female offspring. The observed nest warming trend up to 0.3 and 0.5°C for the last 100 years, which explains the observed sex ratio (Hays et al., 2003). Increasing temperatures shrink male-off spring and threaten the population.

In the section on phenology we already gave several examples of changes in timing of life cycle events in marine systems. In addition, the distribution area of species is changing rapidly in marine ecosystems. RIVM (2003), for example, presents monitoring data of a population increase of the Scaldfish (*Arnoglossus laterna*) and the Lesser weever fish (*Echiichthys vipera*) along the Dutch coast. These species occur from the Mediterranean Sea till the south of Scandinavia but were rare in the North Sea. Beare et al. (2004) analyzed trawl data from Scottish research vessels over the last 75 years. They clearly showed that catches of the warm water pelagic species, Anchovy (*Engraulis encrasicholus*) and Sardine (*Sardina pilchardus*), increased suddenly after 1995. All these increases correlate well with the increase in temperature since the end of the 1980s.

Rappé (2003) described some remarkable observations on marine coastal organisms including autochthonous crabs and shrimps, mollusks and aliens of Belgium. Populations fluctuate during the last two decades following severe or mild weather conditions. They disappear after harsh winters and come back more rapidly than in the past. Some offshore species are stranded or extirpated more often. Species new to the area turn up and establish. These observations are believed to be mainly triggered by changes in the oceanographic/climatic conditions, luring or forcing southern species into the North Sea and its coastal waters. There are similar examples along the American coasts as well (Parmesan and Galbraith 2004).

5.5.1 Impact on foodwebs

Increasing evidence is found that every part of the whole food web in marine systems is undergoing significant changes (European Environment Agency 2004). An important basis of the food chain is zooplankton. Some zooplankton species have shown a northward shift of up to 1000 km, in combination with a major reorganization of marine ecosystems. These shifts have taken place southwest of the British Isles since the early 1980s and, from the mid 1980s, in the North Sea (Beaugrand et al., 2002). In contrast, the diversity of colder temperate, sub-Arctic and Arctic species has decreased. Furthermore, a northward extension of the ranges of many warm-water fish species in the same region has occurred, indicating a shift of marine ecosystems towards a warmer north-eastern Atlantic. An invasion of warm-water species into the temperate areas of the northeast Atlantic has also been observed. For example, the cold-temperate *Calanus finmarchicus* copepods are now rapidly replaced by the warm-temperate *Calanus helgolandicus*. Most of the warm-temperate and temperate species have migrated northward by about 250 km per decade, which is much faster than the migration rates expected in terrestrial ecosystems (Parmesan and Yohe 2003).

5.6 Impacts on coral reefs

Coral reefs are the most diverse marine ecosystem and embrace possibly millions of plant, animal and protist species (Hoegh-Guldberg & Fine, 2004). They have become one of the clearest indicators of climate change’s ecological impacts. Mass coral bleaching - the loss of the dinoflagellate symbionts and their chlorophyl from reef-building corals - and mortality has affected the world's coral reefs with increasing frequency and intensity since the late 1970s. Mass bleaching events, which often cover thousands of square kilometres of coral reefs, are triggered by small increases (+1 to 3°C above mean maximum) in water temperature (Hoegh-Guldberg & Fine, 2004). The temperature regimes of corals used to be very stable covering a range of 3°C between minimum and maximum (Smith et al. 2001). During recent El Niño events, water temperatures in many tropical waters have increased over 5°C, which resulted in massive bleaching events of up to 95% in shallow waters in countries like Sri Lanka, India, Kenya, Maldives, and Tanzania. The last Australian summer (December 2005-March 2006) was the hottest ever recorded. This resulted in very warm sea surface temperatures and extensive bleaching of the colours of the Great Barrier Reef. These impacts was even recorded by satellites (Figure 9) and it will probably take years before these bleached reefs recover. The loss of living coral cover (e.g. 16% globally in 1998, an exceptionally warm year) is resulting in an as yet unspecified reduction in the abundance of a myriad of other species (Hoegh-Guldberg & Fine, 2004).

Furthermore, it is expected that corals on the northern hemisphere will also migrate to northern areas in the Northern Hemisphere in response to the increases in temperature. This has been observed by Precht and Aronson (2004). Both the Staghorn coral (*Acropora cervicornis*) and Elkhorn coral (*Acropora palmata*) are now re-expanding their ranges northward along the Florida Peninsula and into the northern Gulf of Mexico.

The marine species and ecosystems are diverse but less well studies and documented. The first signs of impacts point at a higher sensitivity than land ecosystems. The spread of organisms is probable faster then on land. The impacts are therefore more immediate. There are, however, several large unknowns, such as the impacts of enhanced acifidication of the oceans due to the increased atmospheric CO_2 concentrations, (Raven et al. 2005). This could well disrupt whole marine food chains.

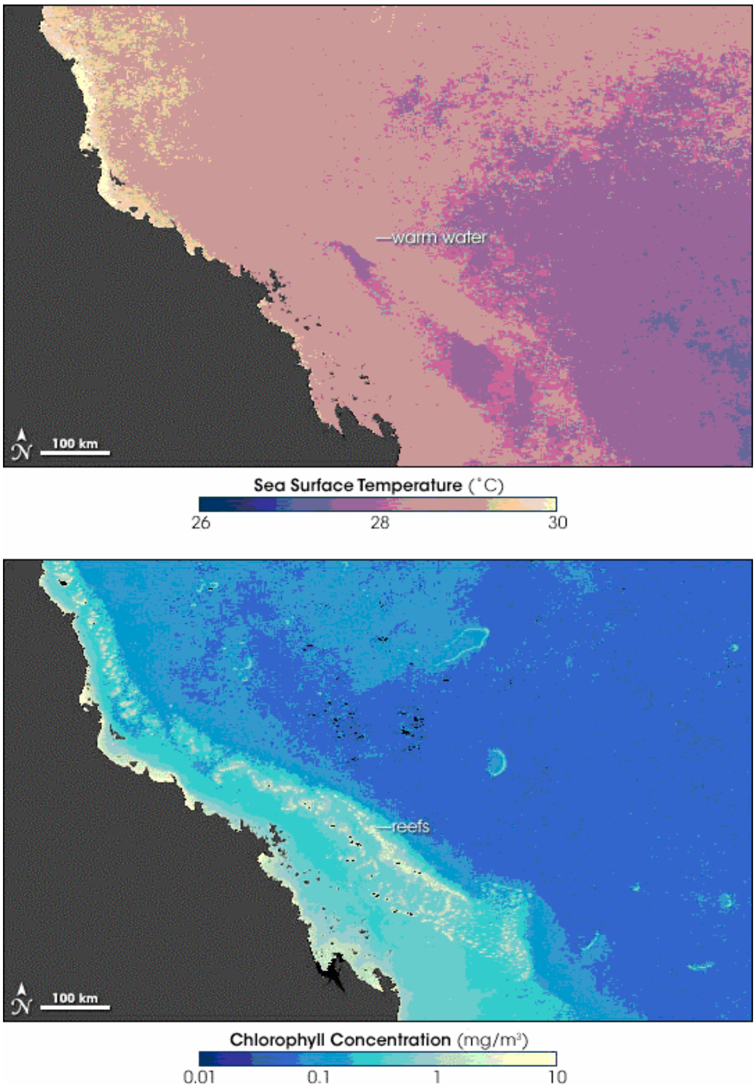

Figure 5.8. Sea surface temperatures and regional coral bleaching as determined by chlorophyll content at the Great Barrier Reef in March 2006. (Source: NASA).

5.7 What to do?

5.7.1 Establishing realistic trends

Van Vliet and Leemans (2006) conclude that traditional impacts assessments (i.e. with models and scenarios) likely underestimate impacts on ecosystems, especially at lower levels of climate change. They motivate this by linking extreme weather events to observed impacts. Extreme weather has changed more pronouncedly then average weather and ecosystems have responded to this more complex set of changes than the average climate change in most climate scenarios. This explains the rapid appearance of ecological responses throughout the world. Unfortunately, most climate scenarios do not provide routinely information on extreme events, although some now start to address this void (e.g. Giorgi, 2006). But this information is not yet used in the impacts studies that assess future impacts. To determine the real vulnerability this is urgently needed.

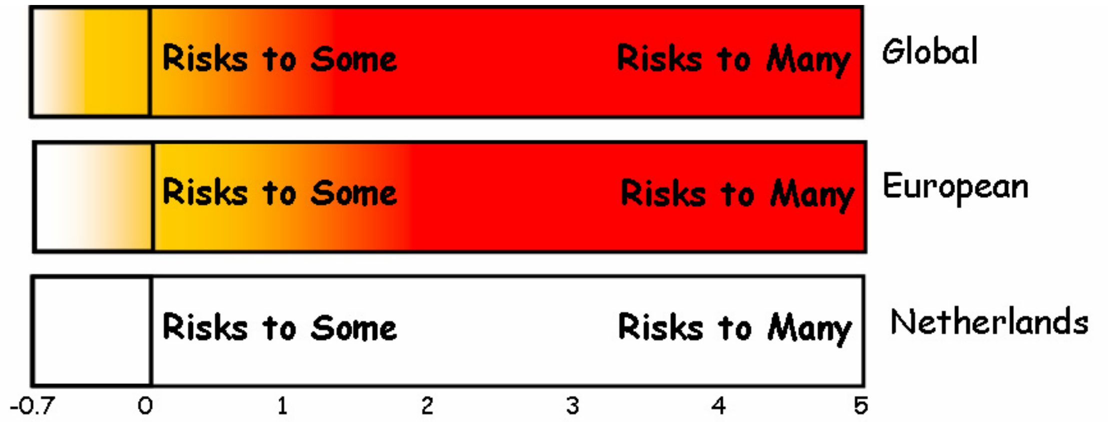

Figure 5.9. The 'Burning Ember' for risks of negative impacts on marine species and ecosystems.

Another limitation of impact studies is the lack of proper indicators. The Millennium Ecosystem Assessment (Carpenter et al., 2005; Reid et al., 2005) concludes that there is not a single indicator to unambiguously measure the impacts of climate change on biodiversity. One needs a number of indicators, including those on *trends in extent of selected biomes, ecosystems and habitats*, *abundance and distribution of selected species* and *incidence of human-induced ecosystem failure*, that can serve to derive trends where more detailed data are not available. Some of those aggregate indicators have been proposed (de Groot et al., 2003; Tekelenburg et al., 2004; Scholes & Biggs, 2005). Because small, fragmented ecosystems are more affected by changes in climate than large contiguous ecosystems with a more balanced micro-climate, trends in *connectivity/ fragmentation of ecosystems* provide an indicator of the vulnerability of ecosystems to climate change.

Most of the convincing observed trends globally, in Europe and in the Netherlands were based on long term monitoring of vegetation (e.g. Tamis, 2005), a group of species (e.g. Kuchlein & Ellis, 1997), or single species (e.g. Both & Visser, 2001; Both et al., 2006). All these monitoring networks were not established to determine the impacts of climate change but for other scientific interests or environmental monitoring. But the impacts of climate change become significant because the impact can be analyzed in the longer term perspective. This makes such rare studies very valuable, convincing and of much broader interest than just their original purpose. Many other short term studies often remain anecdotic.

5.7.2 Reducing vulnerability

Species have no insight in the future changes and only respond to changes in their environment. Only one species, *Homo sapiens*, is an exception and can predict and plan.

Adaptation measures for all other species should therefore be focused on at least maintaining but trying to enhance resilience of species and ecosystems.

The aggregate level of natural habitats, species and genetic diversity is projected to decrease. Thus progress in this target is challenging and depends on protecting those critical habitats, populations of species and genetic diversity that contribute to resilience and/or facilitate adaptation in the face of climate change. There is a need for Parties and other Governments to address this threat, including through their commitments under the United Nations Framework Convention on Climate Change and its Kyoto Protocol, in order to lessen dangerous impacts on ecosystems. At the same time, activities aimed at the conservation and sustainable use of biodiversity (including the development and management of protected areas) also need to fully take into account climate change. Some species and ecosystems, in some regions, may be more vulnerable to climate change and with this in mind, there is a need to develop and implement adaptation measures in all the thematic programmes of work.

To limit the risks for impact of climate change on ecosystems two approaches have to be taken. First, climate change has to be limited by limiting climate change through the reduction of greenhouse gas emissions. A recent analysis shows that this is economically and technologically feasible (Grubb et al., 2006). This study as based on a series of different economic model for the global energy system used to calculate the costs and benefits of emissions reduction scenarios that stabilized concentrations at 400, 450 and 550 ppmv. These concentrations levels are consistent with a maximum global mean temperature increase of 2°C.

Second, the resilience of species and ecosystems has to be increased. There are many ways to achieve this (McNeely et al. 2005). One of the most important strategies is to reduce and rmove the other stresses on ecosystems and enhance conservation efforts (Noble et al. 2005). However, conservation organizations and ecosystem managers are currently poorly prepared for climate change impacts, especially if based solely on static protected areas systems and traditional forestry, agricultural and fishery practices. Responses now remain limited to generalized no-regrets strategies, while a much more pro-active attitude is needed (Chopra et al., 2005).

Finally, the cascade of uncertainties from climate change projections (especially in rainfall patterns) through still developing theory and knowledge of species to ecosystem responses remain significant barriers to developing coherent and detailed regional policy planning responses (McNeely et al., 2005).

5.8 Consequences for the 'Burning Ember'

Many have tried to define the allowable climate change (e.g. Vellinga & Swart, 1991; Swart et al., 1998; Smith et al., 2001; Leemans & Eickhout, 2004; Heij et al., 2005; Hare, 2006; Schellnhuber et al., 2006; van Vliet & Leemans, 2006). The first clause of the objective of the UNFCCC (Article 2) is stabilization of greenhouse gas concentrations. To achieve this means large global emissions reductions (cf. footnote 1). But these concentrations should be stabilized at levels that do not lead to a dangerous human interference with the climate system. For ecosystems, Article 2 specified this as to allow ecosystems to adapt naturally although this is not further defined. UNFCCC therefore allows some limited climate change. They focus on ecosystems, not species. Decline in species and even extinction of species is not banned! But the integrity of ecosystems has to be maintained to allow adaptation at the ecosystem level. The plasticity provided by phenology is one of the examples of such resilience.

The TAR already established in 2001 that beyond 2°C global mean temperature increase the risks for negative impacts on species and ecosystems rapidly increased. This analysis shows that this assessment was too optimistic. Risks for many local and regional species and ecosystems already rapidly increase beyond 1°C (see Figure 5.10).

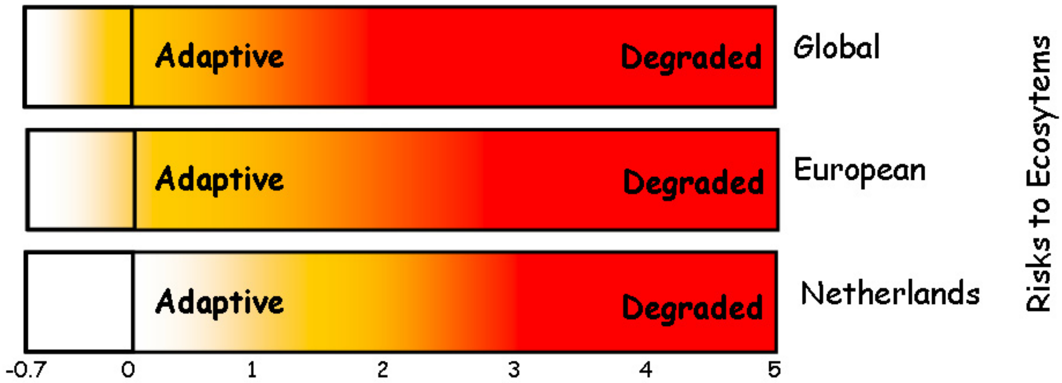

Figure 5.10. The final 'Burning Ember' summarizing the risks for ecosystem impacts.

5.9 Summary and conclusions

The most recent scientific literature shows that climate change impacts may occur earlier than projected by Third Assessment Report of IPCC (TAR). The impacts include changes of the terrestrial carbon balance, which after continuing its role as sink for few decades could change in a source, widespread species geographic shifts, rapid phonological responses of plants and animals, and changes in distribution, structure and composition of most ecosystems (not only in the boreal zone as previously stressed).

There is now growing evidence for a high vulnerability of a larger fraction of species (globally ~25% by 2100, for some biota as low as 1% or as high as 43%) becoming committed to extinction than previously assessed. Changes in disturbance and other stresses such as wildfire, invasive species and pollution are likely to exacerbate climate change impacts.

Responses of endemic species (i.e. unique species confined a small area) geographic range size are overwhelmingly negative with resulting impacts on biodiversity and biodiversity hotspots, and strongly sensitive ecosystems are coral reefs, arctic systems, mountains, Mediterranean systems and savannas. In most cases, species persistence requires migration rates that exceed their natural adaptive capacity. These effects, combined with landscape fragmentation through land use change, limit natural adaptation especially for plant species, and increase their risk of extinction during this century. Marine ecosystems and species appear more able to shift range rapidly than many terrestrial species. All these impacts may lead to mainly detrimental changes in ecosystem services. Impacts on sustainable development and livelihoods of people depending on the ecosystems remain, however, difficult to estimate.

The TAR already established in 2001 that beyond 2°C global mean temperature increase the risks for negative impacts on species and ecosystems rapidly increased. This analysis shows that this assessment was too positive. Risks for impacts on many local and regional species and ecosystems already rapidly increase just beyond 1°C global mean warming and are also not negligible at lower temperature increases.

To limit the risks for impact of climate change on ecosystems two approaches have to be taken. First, climate change has to be limited by limiting and reducing greenhouse gas emissions. This seems economically and technologically feasible. Second, the resilience of species and ecosystems has to be increased. One of the most effective strategies to achieve this is to reduce other stresses on species and ecosystems and enhance conservation efforts. However, the cascade of uncertainties from climate change projections through species to ecosystem responses remains a significant barrier to develop coherent and detailed regional policy planning responses.

6 The Health Effects of Climate Change in the Netherlands

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6.1 The health effects of climate change in the Netherlands

Global climate change is likely to influence human health in various ways (see Figure 6.1). As a result, preventing adverse effects on human health is increasingly being used as a justification for action on climate change. However, population health is nearly invisible in the United Nations Framework Convention on Climate change (UNFCCC; Kovats et al., 2005).

In the policy arena, there is still considerable confusion about what qualifies as 'dangerous' under Article 2 of the UNFCCC. Kovats et al. (2005) concluded that "there is strong evidence that the impact on health would be greater with warming in excess of 2ºC of global mean temperature before the end of this century than warming that remains below this value". However, the various parts of the globe will be affected in very different ways due to differences in sensitivity, exposure and adaptive capacity.

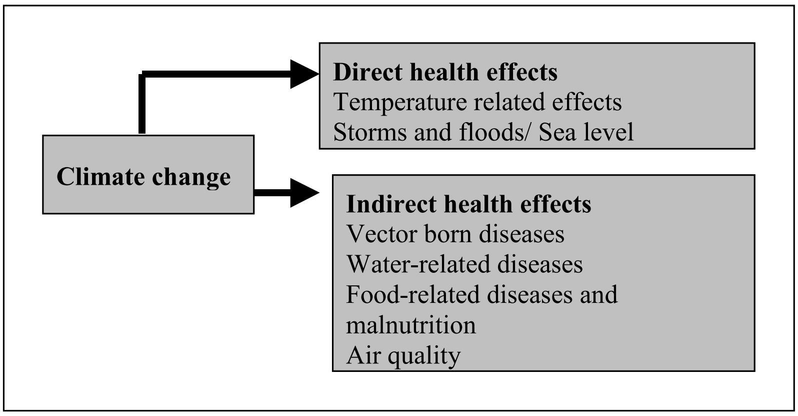

Figure 6.1. Health effects of climate change.

6.2 Indicators

We will look specifically to the Dutch situation and have selected the following three indicators: heat wave mortality, (temperature suitability for) Lyme disease and pollen allergy. This selection is based on the relevance of indicators in terms of severity of health impact in the Netherlands (MNP, 2005) and the attractiveness of the indicator to Dutch stakeholders (i.e. perceived importance) (Gupta & van Asselt (eds.), 2004). See Box 6.1 for an overview of other health effects.

Box 6.1. Climate change in The Netherlands: other health effects (see e.g. Gupta & van Asselt (eds.), 2004; MNP, 2005.

- Storms and floods: In the Netherlands, disease risks from flooding are greatly reduced by a well-maintained sanitation infrastructure and public health measures. Hajat et al. (2003) concluded that in Europe the effect of floods increasing the risk of disease outbreaks appears relatively infrequent, while mental health disorders, like depression and anxiety, are most likely the most important health effect.
- Water-related diseases: It is unlikely that water-borne diseases will become a serious threat in the Netherlands. There may be some health implications, however, due to an increase in imported cases from less developed regions (e.g. cholera) and from bathing in coastal and surface water of poor quality (e.g. blue algae).
- Food-related diseases and malnutrition: Climate change could increase the occurrence of food-born diseases like Salmonella and Campylobact (e.g. the development of microbes in food is temperature-dependent). However, it is unlikely that in the Netherlands any substantial increase in these diseases will be observed due to the high standards with regard to hygiene. Worldwide, food security and malnutrition remain major concerns of climate change, but it is highly unlikely that the Netherlands will be seriously affected.
- Air quality: Weather conditions influence air quality via transport and formation of pollutants and can also influences air pollutant emissions (e.g. increased energy demand). Air pollutant problems due to climate change are expected to be more serious in cities. The expected increases in summer days and tropical days could result in higher SMOG-related health risks in summer.
- Malaria: With regard to malaria, there may be an increase in risk of occasional local P. vivax summer epidemics and it is also possible that the Mediterranean vector An. labranchiae may expand into central and western Europe, presenting a potential for P. falciparum malaria infections. However, the chances of the return to a situation of endemic malaria in the Netherlands remain very low due to, for example, an excellent health care system. There could be health implications as a result of the import of malaria cases from less developed regions.

6.2.1 Heat wave mortality

Many studies have shown the relationship between temperature and premature death. A Dutch study carried out by Huynen et al. (2001) revealed that in the Netherlands, this relationship has a ‘V shape’, with an optimum temperature (the average day temperature with the lowest mortality) of 16.5°C. Above and below this optimum mortality increases. The direct influence of temperature on health is demonstrated by the observed increase in mortality during past heat waves. During the Dutch heat waves of 1982, 1983, 1990, 1994, 1995 and 1997, the extremely high temperatures resulted in an average of 38.9 excess deaths per day or an excess mortality of 12.8% (Huynen et al., 2001). This latter percentage is in line with other studies (Sartor et al., 1995; McMichael & Kovats, 1998; Rooney et al., 1998). The Dutch heat wave of August 2003 lasted about 2 weeks. Compared with the mortality rate during a normal August (with a mean temperature of about 22ºC), Statistics Netherlands concluded that about 400–500 extra deaths occurred due to the extreme heat in this period (de Beer & Harmsen, 2003). The increased mortality probably also implies an increase in morbidity, the size of which is at least proportional to that of the increased mortality and probably greater (MNP, 2005). The elderly (65+), people with respiratory conditions and people with cardiovascular diseases are particularly sensitive to extreme heat. In many countries the population is ageing, resulting in an increase in the population vulnerable to heat stress. Climate change exerts an added effect. Babies and young children possibly form a risk group as well, because their temperature regulation still needs to develop and dehydration can occur very quickly. However, little information is available about the effects of heat waves on babies and young children.

Still, the figures need to be put into perspective, as not all heat-related deaths results in significant loss of life; part of the excess mortality during heat waves must be viewed as ‘only a slight forward displacement of deaths’. As a result of this forward displacement of deaths, a temporary fall in mortality is often observed in the weeks following a heat wave. The other part of the excess mortality, however, relates to avoidable deaths and substantial loss of life. Unfortunately, little is currently known about the ratio between these two groups.

6.2.2 Lyme disease

A rather new tick-born disease called Lyme disease is increasingly prevalent in much of Europe, including the Netherlands. This bacterial infectious disease is caused by the spirochaete *Borrelia burgdorferi* and is transmitted by *Ixodes ricinus* (i.e. the sheep tick). This vector is endemic in the Netherlands (van der Poel et al., 2005). Climate change is expected to influence tick distribution/density/activity (see e.g. Lindgren et al., 2000; IPCC, 2001; Lindgren & Jaenson, 2006; Ogden et al., 2006) and, consequently, disease risk. Countries in Northern Europe are vulnerable to increased incidence of Lyme disease, and Lyme disease is likely to be the vector-borne disease most important in an European context in relation to climatic changes (Kovats et al., 2003).

Lyme disease has an unpredictable clinical course that presents many symptoms. If treated insufficiently, or too late, it can lead to severe disability and illness. Risk groups are people who spend a lot of time in gardens, parks and woods, thereby increasing their chances of being bitten by an infected tick. In Norway, Lyme incidence is highest in children aged 5-9 (Nygard et al., 2005).

Between 1994 and 2001, the estimated number of tick bites in the Netherlands doubled from 30,000 to 61,000. The number of patients with a bull's-eye shaped rash on the skin- as an early symptom of the disease (erythema migrans) - also increased by about a factor of two, which indicates that the risk of infection is rapidly increasing. The increasing popularity of outdoor recreation is believed to be one of the most important causes (den Boon & van Pelt, 2003). However, some argue that in, for example, Sweden the increased density and geographical range of *Ixodes ricinus* in the 1990s can be attributed to the milder climatic conditions (Lindgren et al., 2000).

The distribution and population density of ticks dependents on various factors. Studies on the relationship between climate conditions and tick borne diseases have mostly focused on climate/weather effects on the vector (e.g. Lindgren et al., 2000; Ogden et al., 2004). A few studies focused on the relationship between disease incidence (e.g., Lyme Disease, Tick-Borne Encephalitis) and temperature, precipitation and/or moisture (Lindgren, 1998; Lindgren & Gustafson, 2001; Subak, 2003). Pathogen distribution appears to be mainly determined by biotic factors, such as sufficient tick densities (Cortinas et al. 2002). For this study, we focus on the influence of climate change on tick density, as the abundance of host-seeking nymphs is positively and significantly correlated with the incidence of reported human Lyme disease (Stafford et al., 1998). Due to the complex multi-stage life cycle of the *Ixodes ricinus* tick, several bioclimatic thresholds influence tick density. Very cold winters, for example, negatively influence vector survival (Lindgren et al., 2000; Lindgren & Gustafson, 2001; Subak 2003; Ogden et al., 2004; Lindgren & Jaenson, 2006), as well as extremely high temperatures (Ogden et al., 2004). Besides vector survival, vector activity is also an important determining factor for tick density and, subsequently, disease transmission. The transmission of the causal bacteria mainly takes place in spring, summer and autumn, when ticks are most active (Lindgren et al., 2000; Subak, 2003). Lindgren et al. (2000) investigated the relationship between several bioclimatic temperature thresholds (number of days above/below specific minimum temperature levels) and tick density in Sweden. Table 6.1 gives an overview of these important temperature thresholds.

Table 6.1. Bioclimatic (temperature) thresholds for Ixodes ricinus, the tick responsible for the transmission of Lyme disease.

Temperature threshold*	Explanation
Tmin< -10°C, or Tmin< -12°C	Threshold for winter survival. In Sweden, tick density has been related to fewer cold days in winter (Lindgren et al. 2000).
Tmin > 5°C	Threshold for tick activity and vegetation season. In laboratory settings, tick development is very sensitive to temperature changes below 5 degrees (Ogden et al., 2004). In southern Sweden, increases in tick density have been related to more days with early spring and late autumn temperatures (T min between 5-8°C) (Lindgren et al. 2000). The relative length of the tick season is a risk factor for tick bites (Stafford et al., 1998).
Tmax> 30	Threshold for summer survival/development. In laboratory settings, higher temperatures have a negative effect on developing ticks and egg quality, a factor that may constrain the southern geographical range of the tick (Ogden et al., 2004). This threshold is, however, not adequately studied in the field; it is possible that ticks might survive during high maximum temperatures due to the influence of ground cover on the micro-climate.

*Tmin=minimum temperature; Tmax=maximum temperature.

In addition, ticks require humid micro-climatic conditions. As a result, soil humidity and ground cover are important factors in vector survival (Subak, 2003). According to Lindgren et al. (2000), however, precipitation is less important than ground cover for maintaining adequate humidity. They conclude that between temperature thresholds, land use factors are most important.

It is important to note that sheep ticks can also transmit other infectious diseases such as Tick-Borne Encephalitis (TBE). A Dutch study concluded that there is no unambiguous evidence that the TBE virus is endemic in ticks or wildlife in the Netherlands. No endemic infection has ever been observed in a Dutch inhabitant. Climate changes may affect/influence TBE virus transmission cycle and significantly increases TBE virus prevalence in Germany, not far from the Dutch border. The chance of introduction into Dutch regions is high and, consequently, the TBE virus can become a significant pathogen (van der Poel et al., 2005).

6.2.3 Pollen allergies (hay fever)

Allergic conditions seem to be increasing in Europe for reasons that are still unknown. These conditions include allergic hay fever (with a running nose and sneezing). Pollen related allergic diseases may account for 10-20% of allergic diseases in Europe. Climate changes and weather conditions affect the timing and perhaps also the duration of the pollen season, the quantity of pollen produced and the geographic distribution of flowering plants. The prevalence of hay fever is therefore often correlated with the pollen season (Huynen & Menne, 2003). Climatic changes in the Netherlands and their possible effect on pollen production can, therefore, have a direct negative effect on allergic conditions such as hay fever and asthma, and on the number of patients affected by these diseases. For example, plants require a certain amount of accumulated heat to complete the flowering phase. Van Vliet et al. (2002) have demonstrated a strong correlation between temperature and start of the pollen season in the Netherlands. Other European studies, in Denmark (Rasmussen, 2002) and Switzerland (Frei, 1998), found trends to increasing amounts of pollen over the past decades, that were related to climate change. In addition, climate change potentially affects the European distribution of allergen-producing species (Beggs 2004).

Although an effect of climate on pollen seems likely, there are insufficient quantitative data to predict the size of this. However, in the Netherlands, climate-induced changes in pollen exposure may affect a large number of people. From a health point of view, these can be important effects because such conditions are already major causes of morbidity, loss of productivity, and increasing healthcare costs in some European countries (Huynen & Menne, 2003; MNP, 2005).

6.3 Adaptation options

A population's adaptive capacity concerns the ability to adjust to climate change in order to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. It is determined by factors like economic resources, technology, information and skills, infrastructure, institutions and equity (WHO, 2003). Most assessments of the health impacts of climate change have not addressed adaptation explicitly. Table 6.2 shows that possible adaptation strategies to mitigate the health effects of climate change cover a wide spectrum. A simple example is that of reducing the extra deaths and episodes of serious illness experienced by urban populations during extremes of heat. Adaptations could include 'weather-watch' warning systems, better housing design, climate-related urban planning (to reduce the 'heat island effect'), and greater access to emergency medical care. For Lyme disease, no adequate vaccination is available yet. Important preventive measures include wearing protective clothing, using insect repellent and early detection and removal of ticks (Nygard et al., 2005). Little is known about the biological or passive adaptation of humans to climate change.

During a participatory workshop in Utrecht in 2001, Dutch stakeholders (e.g. health professionals, policymakers, interest groups, scientists) discussed that the Netherlands will to some extent be capable of coping with possible health effects resulting from climate change (Van Ierland et al., 2001). Possible measures that they frequently mentioned to reduce the impacts included education and monitoring. Much can be gained through preventive healthcare, such as improved knowledge combined with financial incentives that result in adaptive behaviour. Special attention has to be paid to vulnerable sub-groups. The group of stakeholders largely disagreed, however, about the question whether or not the adaptation strategies could be realised with limited extra investments or not. More research into the cost-effectiveness of these various adaptation options is therefore required.

Table 6.2. Adaptation options for reducing the health impacts of climate change: heat wave mortality, Lyme disease and pollen allergies.

Health outcome	**Legislative**	**Technical**	**Educational-Advisory**	**Cultural and Behavioural**
Heat wave mortality	Building guidelines, greater access to (emergency) medical care	Housing, public buildings, air-conditioning, urban planning	Early warning systems, maintain hydration, surveillance and monitoring	Clothing, siesta
Pollen allergies	Planning laws (e.g. land use)	Land use planning	Early warning systems, surveillance and monitoring	Remain indoors
Lyme disease	Greater access to medical care; no vaccine available yet	Vector control, habitat control (land use)	Public education campaign, surveillance and monitoring	Self-inspection for tick-bites and early-removal of ticks

Source: Adapted from the cCASHh website[51] and McMichael & Githeko (2001).

[51] cCASHh website Climate Change and Adaptation Strategies for Human Health in Europe. Available at: http://www.who.dk/ccashh. Last accessed April 10 2004.

6.4 Acceptable thresholds

Policy measures are necessary when health risks are considered to be undesired or unacceptable. 'Health risk' is generally taken to be the probability of injury, disease or death under specific circumstances (Hunter, 2003). Subsequently, the acceptable health risk concerns the accepted level of this probability. In Dutch environmental policy, the chance of death is the dominant factor in establishing standards. With regard to hazardous substances without a threshold (i.e. without a value below which effects are unlikely to occur)) the Maximum Permissible Risk (MPR) of dying is 'one in a million per year'. For other substances the MPR is the same as the health-based advisory guidelines (RIVM, 2001).

One other definition of acceptable risk, which is widely accepted in environmental regulations, is the acceptable lifetime risk on morbidity. For example, the US Environmental Protection Agency (acceptable lifetime risk of developing cancer= 10^{-6}) and the World Health Organization (acceptable lifetime risk of developing cancer= 10^{-5}) both use the lifetime risk of becoming ill in order to set standards for carcinogen concentration in drinking water (Cotruvo, 1988; WHO, 1993). Of course, the acceptable lifetime risk on morbidity depends on the nature of disease but is likely to be higher than one in a million (10^{-6}) for diseases less severe than cancer. Another sensible approach would be to consider accepted health impacts in terms of the total disease burden of a population and to define the acceptability in terms of falling below an arbitrary defined level. However, in reality some difficulties might arise when adopting this approach (Hunter & Fewtrell, 2001).

The public based approach towards accepted health risks is based on what is acceptable to the general public. Perceived risks often do not agree with factual/scientific risks assessments. Bennet (1999) identified several 'fright factors' that influence the public's concern about risks and the public's risk. With regard to climate change, health risks deemed to be less accepted due to the nature of the climate change problem (e.g. involuntary, unfamiliar, man-made, the cause of hidden and irreversible damage, scientific uncertainty).

In addition, acceptable health risk can also be defined using an economic approach. Economically defined, the acceptable risk is 'any risk where the costs of reducing that risk exceeds the financial and utility benefits that would arise from that reduction and where such resources required in this risk reduction would not be better spent on other public health issues' (Hunter & Fewtrell, 2001). In the Netherlands, the need to include economic consequences in health risks assessments is recognized (RIVM, 2001).

Table 6.3 gives an overview of possible acceptable risk levels with regard to the health impacts of climate change. These can be viewed as normative threshold levels of climate change induced heat wave mortality, Lyme disease, and pollen-related allergic disorders.

Table 6.3. Acceptability thresholds for heat wave mortality, Lyme disease and pollen allergy.

Indicator	Acceptable risks	Lower acceptability threshold	Upper acceptability threshold
Heat wave mortality	Stakeholder view: mortality remains at current levels (Gupta & van Asselt (eds.), 2004).	Stakeholder view: no increase in mortality (i.e. no increase in the chance of dying) (Gupta & van Asselt (eds.), 2004).	Based on Dutch policy for harmful substances without a threshold: acceptable annual risk of dying (MPR)= one in a million. With a Dutch population of circa 15 million in 1990, this threshold corresponds to 15 excess heat wave deaths per year.
Lyme disease	Stakeholder view: an increase in the chance of falling ill (Gupta & van Asselt (eds.), 2004).	Stakeholder view: If adaptation is no longer possible, or if the costs for adaptation are out of proportion (Gupta & van Asselt (eds.), 2004).	Acceptable lifetime risk on morbidity depends on the nature of disease but is likely to be higher than one in a million (10^{-6}) for diseases less severe than cancer. For this study, we choose an acceptable lifetime risk on Lyme disease of 10^{-5}. This is an arbitrary choice, and more research is required.
Pollen allergies	-	Stakeholder view: structural increase in chronic sicknesses. However, stakeholders did not further explain what this exactly means (Gupta & van Asselt (eds.), 2004).	Information not available; acceptable lifetime risk on morbidity depends on the nature of disease but is likely to be significantly higher than one in a million (10^{-6}) for diseases far less severe than cancer, such as allergies.

6.5 Dangerous health effects of climate change

This section explores the health impacts of a 1, 2 and 3°C temperature rise in 2100, and evaluates these impacts in the light of the identified acceptable thresholds. It focuses on heat wave mortality and Lyme disease. Due to inadequate knowledge, such an analysis is not carried out for the climate change impacts on pollen allergies.

6.5.1 Climate change and heat wave mortality

Figure 6.2 shows the heat wave scenarios used for this study, based on historical daily temperature data for the period 1961-1990; the different scenarios are a result of adding respectively 1, 2 and 3°C to this data set. The underlying assumption is that climate variability will remain the same (which is rather conservative). The number of heat waves per 30-year period remains 5 for the +1°C and +2°C scenarios, but slightly increases to 6 in the +3°C scenario. Average heat wave length increases, however, from 12.2 days to respectively 12.8, 14.4 and 18.3 for the different scenarios.

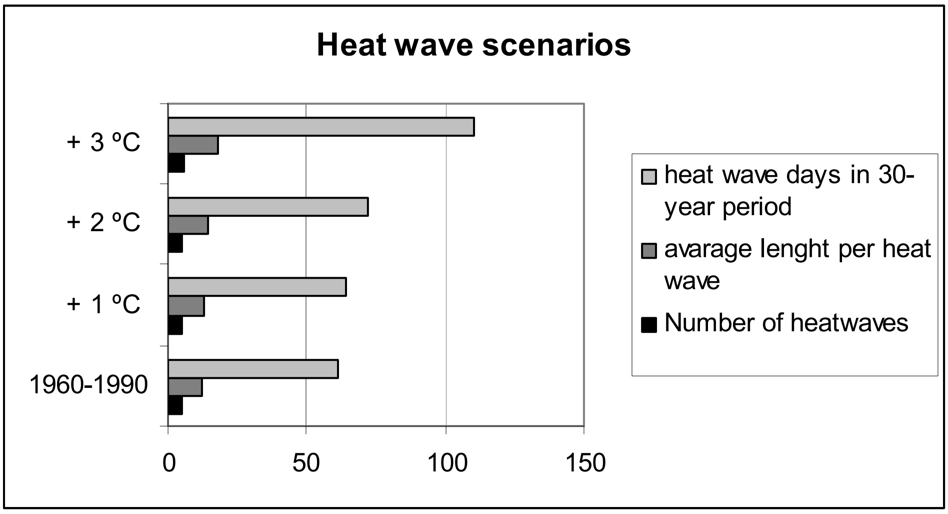

Figure 6.2. Heat wave scenarios for a 1, 2 and 3°C temperature rise compared to 1961-1990 (the different scenarios are a result of adding respectively 1, 2 and 3°C to the historical daily temperature data for the period 1961-1990).

If the population size and structure remain constant, total heat wave mortality in a 30-year period increases to 2547 for the +1 scenario, 2866 for the +2 scenario and 4378 for the +3 scenario (based on an excess mortality of 39.8 per heat wave day, see Huynen et al. (2001). It is important to note, however, that these figures do not take the 'forward displacement of deaths' into account. So only part of the increase in excess mortality will concern avoidable deaths and substantial loss of life. In addition, they do not take any physiological adaptation (autonomous adaptation) or other adaptation options into account. Table 6.4 shows the average annual excess heat wave mortality resulting in real loss of life under several different assumptions regarding the percentage 'forward displacement of death' and adaptation capacity. These assumptions are rather arbitrary and more research into this area is required. However, Table 6.4 shows that under various assumptions, the upper acceptability threshold will be exceeded with a temperature rise of +3°C. The lower threshold will be exceeded with every temperature change; based on this lower threshold, climate change is only acceptable if adaptation will prevent all climate change induced heat wave deaths.

6.5.2 Climate change and Lyme disease

The different climate scenarios used in this section are the result of adding respectively 1, 2 and 3°C to the historical daily temperature data for the period 1961-1990. The underlying assumption is that climate variability will remain the same. We focused on climate change induced changes in the number of days per year below or above important temperature thresholds for tick density (as a proxy for disease risk).

In the period 1961-1990, the Netherlands witnessed 125 days with a minimum temperature (Tmin) of or below -10°C (4.2 days per year), and 54 days with a Tmin of or below -12°C (1.8 days per year). Table 6.5 shows that these numbers will decrease under the various climate change scenarios, which will improve the conditions for tick survival (including egg, larvae and nymphal survival) during winter. With regard to high maximum temperatures in the summer, the Netherlands experienced 72 days in 1961-1990 with a maximum temperature of at least 30°C (2.4 days per year). The table below shows that this number increases under the different climate change scenarios, which could have a negative affect on developing ticks. This threshold is, however, not adequately studied in the field; it is possible that ticks might survive during high maximum temperatures due to the influence of ground cover on the micro-climate. More research into this maximum threshold temperature is, therefore, required.

Table 6.4. Number of excess heat wave deaths resulting in real loss of life, averaged per year, under different assumptions.

Assumptions regarding 'forward displacement of deaths' and adaptation.	Excess heat wave deaths resulting in real loss of life, averaged per year (climate change induced heat wave mortality compared to 1961-1990)*			
	1961-1990	+1 °C	+2 °C	+3 °C
A. No forward displacement of deaths (38.9 excess deaths per heat wave day)**	80.9	84.9 (+4)	95.5 (+14.6)	145.9 (+65)
B. No forward displacement of deaths Autonomous adaptation and extra adaptation measures prevent 75% of climate change induced heat wave mortality	80.9	81,9 (+1)	84,6 (+3.7)	97,2 (+16,3)
C. Forward displacement of death accounts for 50% of excess deaths	40.5	42.5 (+2)	47.8 (+7.3)	73.0 (+32.5)
D. Forward displacement of death accounts for 50% of excess deaths Autonomous adaptation prevents 15% of climate change induced heat wave mortality	40.5	42.2 (+1.7)	46.7 (+6.2)	68.1 (+27.6)
E. Forward displacement of death accounts for 50% of excess deaths Autonomous adaptation and extra adaptation measures prevent 50% of climate change induced heat wave mortality	40.5	41,5 (+1)	44,2 (+3,7)	56,8 (+16,3)
F. Forward displacement of death accounts for 50% of excess deaths Autonomous adaptation and extra adaptation measures prevent 75% of climate change induced heat wave mortality	40,5	41,0 (+0,5)	42,3 (+1,8)	48,6 (+8,1)
G. Forward displacement of death accounts for 75% of excess deaths	20.2	21.2 (+1)	23.9 (+3.7)	36.5 (+16,3)
H. Forward displacement of death accounts for 75% of excess deaths Autonomous adaptation and extra adaptation measures prevent 15% of climate change induced heat wave mortality	20.2	(21,1) (+0,9)	23,3 (+3.1)	34,1 (+13,9)

* = climate change induced heat wave mortality exceeds upper acceptability threshold (=15).

= climate change induced heat wave mortality exceeds lower acceptability threshold (= 0).

**based on Huynen et al. (2001), and assuming constant population size and structure.

Table 6.5. Climate change and Lyme disease: winter and summer. temperature thresholds of ticks (the different scenarios are a result of adding respectively 1, 2 and 3°C to the historical daily temperature data for the period 1961-1990).

Climate change scenario	# days Tmin ≤ -10°C, per year (% change compared to 1961-1990)	# days Tmin ≤ -12°C, per year (% change compared to 1961-1990)	# days Tmax ≥ 30°C*, per year (% change compared to 1961-1990)
1961-1990	4.2	1.8	2.4
+1°C	3.0 (-29%)	1.3 (-28%)	4.2 (+75%)
+2°C	1.8 (-64%)	0.9 (-50%)	4.2 (+75%)
+3°C	1.3 (-69%)	0.5 (-72%)	9.6 (+ 300%)

* This threshold is based on laboratory observations only.

Figure 6.3 shows that climate conditions become more favourable for tick activity, possibly extending the tick season into the winter. The annual percentage of days with a minimum temperature of at least 5°C increases from 53.8% in 1961-1990 to 60.1%, 65.7% and 71.4% for the +1, +2 and +3 °C scenarios, respectively.

As mentioned before, tick density is not only determined by ambient temperature, but also by microclimatic conditions such as humidity. As a result, ground cover also plays an important role, and should ideally be included in climate change impact studies concerning Lyme disease in the Netherlands.

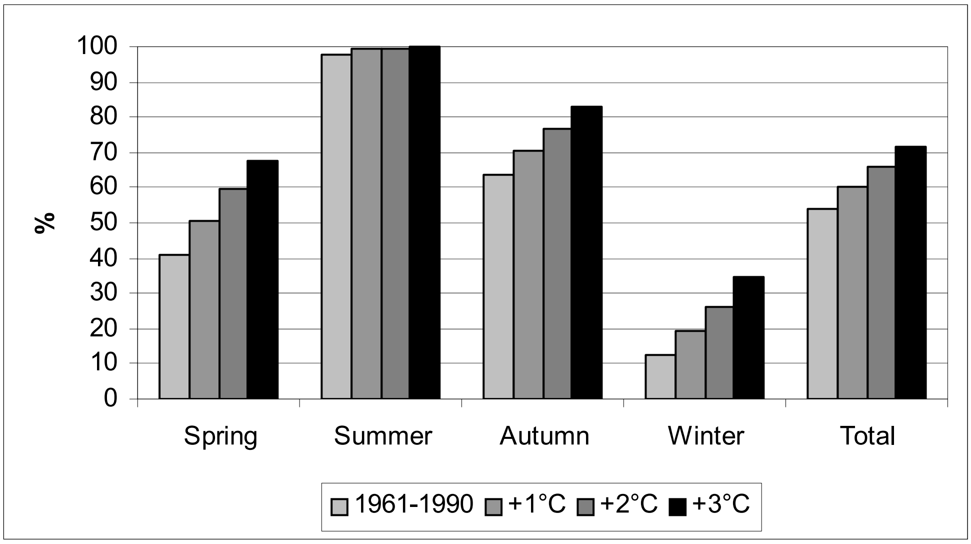

Figure 7.3. Tick activity: percentage of days with a minimum temperature of at leas 5°C, per season (the different scenarios are a result of adding respectively 1, 2 and 3°C to the historical daily temperature data for the period 1961-1990).

To summarise, winter conditions for tick survival will become increasingly favourable under the +1, +2 and +3°C scenarios. During the summer months, high maximum temperature will also become more frequent, which could negatively affect tick survival/development, but more field-research into the maximum threshold is required: it is possible that ticks might survive during high temperatures due to the influence of ground cover on the micro-climate. In addition, Figure 7.3 shows that the number of days with a minimum temperature of at least –5°C will significantly increase, especially during spring, autumn and even winter, indicating a prolongation of the tick season. This would mean an extension of the tick-season with, respectively, 11.7%, 22.1% and 32.7% for the +1, +2 and +3°C scenarios.

In addition, human contact with ticks is likely to increase as a result of climate-induced changes in outdoor recreation. It is also important to note that the vast increases in tick-bites and Lyme disease in the past decade (den Boon & van den Pelt, 2003) indicate that adaptation/prevention might be difficult.

Given the expected increases in winter-survival and the duration of the tick-season, we hypothesize that an increase of at least 1% in the incidence of Lyme disease might be probable under all scenarios, even if adaptation measures are taken in response to the changing climate. In the Netherlands, 17,000 people were diagnosed with Lyme disease by their family doctor in 2005 (RIVM, 2006). Consequently, if climate change would result in a 1% increase in Lyme disease prevalence, an additional 170 persons would become ill every year, and the lifetime risk on morbidity due to climate change would become unacceptable. However, this example of an increase of 1% in disease incidence is an arbitrary choice for illustrative purposes. Although several studies indicate a relationship between the number of days above/below certain threshold temperatures, more research into the exact quantification on these relationships (for the Netherlands) is still required. In addition, it has to be further investigated how expected increases in tick density can be translated into specific disease risks under various assumptions regarding adaptive capacity. More research into the interactions between climate conditions and ground cover in relation to tick density is also required, as well as research into to the climate change conditions that might result in a decrease of disease risk (e.g. extreme heat, and flooding).

6.6 Scientific robustness and gaps in knowledge

6.6.1 Heat wave mortality

Based on Table 6.6 it can be concluded that several epidemiological studies have indicated and quantified the relationship between heat waves and excess mortality. In addition, the view that climate change has an impact on heat wave mortality is well established, although more research into the specific Dutch situation, forward displacement of deaths, (autonomous) adaptation capacity, interactions with air quality (e.g. smog), and heat wave morbidity is required. Overall, it can be concluded that the scientific basis underlying the provided quantitative analysis regarding climate change and heat wave mortality in the Netherlands is speculative/intuitive.

6.6.2 Lyme disease

Based on Table 6.7, it can be concluded that the expectation that climate change has an impact on Lyme is well established, although more research into the specific Dutch situation, the quantification of the relationship between current and future climate conditions and disease risk, the interactions with land use/vegetation, and adaptation capacity is still required. Overall, it can be concluded that the scientific basis underlying the provided quantitative analysis regarding climate change and Lyme disease in the Netherlands is speculative/intuitive.

Table 6.6. Climate change and heat wave mortality: Evaluation scientific basis.

Topic	Scientific basis	Explanation/ research gaps
Influence of climate/temperature on mortality	Well-established	Many studies have shown the relationship between temperature and premature death.
Exposure-impact relationship: excess mortality during heat waves	Well-established	Several studies indicate an excess mortality of 12-15% (Huynen et al., 2001; Sartor et al., 1995; McMichael & Kovats, 1998; Rooney et al., 1998). It is important to note that more research is required on the interactions with air quality, and on heat wave morbidity.
Forward displacement of death	Anecdotal	Scientists agree about the existence of this phenomena (e.g. (Sartor et al., 1995; McMichael & Kovats, 1998; Rooney et al., 1998; Huynen, 2003)), but more research is required into the ratio between the merely forward displaced deaths and the avoidable deaths that result in real loss of life.
Effect of climate change on heat wave mortality is expected	Well-established	See e.g. the IPCC report on climate change impacts (IPCC, 2001).
Exposure-impact relationship between climate change and heat wave mortality in the Netherlands	Speculative/intuitive	More research is required specifically looking at the Dutch situation, including adaptation capacity and projected heat wave occurrence/length under different climate change scenarios.
Acceptability threshold	Anecdotal Speculative/intuitive	More (participatory) research required.

Table 6.7. Climate change and Lyme disease: Evaluation scientific basis.

Topic	Scientific basis	Explanation/ research gaps
Climate dependency of tick density and activity, and, consequently, disease risk	Well-established	Several studies indicate temperature and moisture effects on the vector (e.g. Lindgren et al., 2000). A few studies focused on the relationship with disease incidence (e.g. Subak, 2003).
Exposure-impact relationship between climate conditions and Lyme disease	Speculative/intuitive	The exacts size of the relationship between climate/temperature and disease risk is not well-established, and still needs further research to improve quantification.
Interaction between climatic conditions, ground cover and tick density/activity	Anecdotal	Only a few studies look at this interaction, by means of, for example, Geographical Information Systems (GIS) and modelling (Guerra et al., 2002)
Influence of climate change on tick density and, subsequently, disease transmission is expected	Well-established	Several publications discuss an expected effect of climate change on tick density and disease risk (e.g. (Lindgren et al., 2000; Lindgren & Jaenson, 2006; Ogden et al., 2006)).
Exposure-impact relationship between climate change and Lyme disease	Speculative/intuitive	More research is required specifically looking at the Dutch situation, including adaptation capacity and projected changes in habitat/temperature suitability for ticks under different climate change scenarios.
Acceptability threshold	Anecdotal Speculative/intuitive	More (participatory) research required.

6.6.3 Pollen allergies

Weather affects pollen production, emission, transport and deposition. However, the effect of climatic conditions on allergies has been investigated only in very few studies (see Huynen and Menne (2003) for an overview), but the findings suggest that climate (change) may affect the prevalence of allergies in children and adults. In January 2003, a workshop was organised at the World Health Organization office in Rome. The participants formed a multidisciplinary group with expertises in epidemiology, medicine, allergology, pediatrics, meteorology, aerobiology, phenology and environmental health. The meeting concluded that the impact of climate change on the incidence, prevalence, distribution and severity of allergic disorders is uncertain and there is a need to better understand the relationship between the changing climate and allergic disorders.

Several important research gaps were identified, which can be summarised as follows (Huynen & Menne, 2003):

- There is a need for more studies on the relation between long-term climatic conditions, phenological changes and disease prevalence and incidence. Especially, the lack of knowledge on incidence is considered to be a gap. Studies should also look at other health outcomes, such as exacerbation, severity and seasonality of diseases.
- There is a need for long term studies on dose-response relationships, although it is recognised that performing such studies would be a huge effort; they would involve measurements, monitoring and analysis within several subpopulations in Europe and an extensive infrastructure to obtain existing and new data.
- Investigations have shown that warming will lead to an earlier start of the season, but will it also lead to a prolongation of the season or changes in intensity?
- The pollen-allergy relationship is a multi-factorial process and research into the multiple interacting factors that affect allergic disorders is required.
- Models need to be developed to explore the future.

In addition, more (participatory) research is required on determining the acceptability threshold.

6.7 Conclusions/summary

The different climate scenarios used in this section are the result of adding respectively 1, 2 and 3°C to the historical daily temperature data for the period 1961-1990. Our findings can be summarized as follows:

- **Heat wave mortality:** The view that climate change will have an impact on heat wave mortality is well established. Under various assumptions regarding the percentage 'forward displacement of death' and adaptation capacity, the upper acceptability threshold (annual risk of dying is one in a million) will be exceeded with a temperature rise of +3°C. The lower threshold (no increase in mortality) will be exceeded with every temperature change. More research into the specific Dutch situation, forward displacement of deaths, (autonomous) adaptation capacity, interactions with air quality (e.g. smog), and heat wave morbidity is required.
- **Lyme disease:** The expectation that climate change will have an impact on Lyme is well established. Winter conditions for tick survival will become increasingly favourable under the +1, +2 and +3°C scenarios. The increasing number of days with a minimum temperature of at least –5 °C will significantly increase, indicating a prolongation of the tick season. We hypothesize that an increase of at least 1% in the incidence of Lyme disease is probable under all scenarios, even if adaptation measures are taken. Consequently, the lifetime risk on Lyme disease due to climate change would become unacceptable. More research into the specific Dutch situation, the relationship between (future) climate conditions (incl. maximum temperature threshold) and disease risk, the interactions with land use/vegetation, and adaptation capacity is still required.
- **Allergies:** Climate change can affect the timing/duration of the pollen season, the quantity of pollen produced and the geographic distribution of flowering plants. Although an effect of climate on pollen seems likely, there are insufficient quantitative data to predict the size of this. However, in the Netherlands, climate-induced changes in pollen exposure may affect a large number of people. The impact of climate change on the incidence, prevalence, distribution and severity of allergic disorders is uncertain and there is a need to better understand the relationship between the changing climate and allergic disorders.

7 Climate Impacts on the Coastal Zone

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7.1 Introduction

The coastal zone is an essential part of the Netherlands, providing and supporting many socio-economic functions and ecological values. Examples of this are tourism and recreation, fishery, aquaculture, ports and harbours, and coastal wetlands. As a result the coastal system is under continuous pressure to provide room and space for these functions and values and to safeguard their sustainable co-existence. Climate change affects the coastal zone in terms of sea level rise and a possibly changing wind climate resulting in changing storm frequencies and magnitudes.

Worldwide major concerns are rapid urbanisation in coastal plains in combination with an ongoing sea level rise, both being gradual, but steady developments (Bird, 1993, Douglas 2001). Based on IPCC calculations, Nicholls (2004) considers the implications of a range of global-mean sea-level rise and socio-economic scenarios on: (1) changes in flooding by storm surges; and (2) potential losses of coastal wetlands through the 21st century. He concludes that both depend very much on local economic growth and suggests that more attention needs to be paid to the role of development pathways in influencing the impacts of climate change needs to be given more attention.

7.1.1 Sea level

Current levels of sea level rise lie in the range of 9-88 cm up to 2100 compared to 1990 (IPCC, 2001). In about 3000 years models predict even sea levels of 2 to 4 m above the current level depending on the CO_2 emissions taking place (IPCC, 2001). The main cause is global warming expanding the volume of seawater on a time scale of thousands of years. The reason for this long timescale is that the expansion lags behind changes in temperature due to long-term ocean mixing processes. Additionally, due to melting of glaciers and icecaps on Greenland and the Antarctic extra (fresh) water discharges into the ocean. The melting process of glaciers and ice caps water has a direct impact on the sea level. This means that the uncertainty related to the glacier and ice cap melting increases the uncertainty on the rate of sea level rise to be expected. Although this uncertainty is included in the 15-85 range of IPCC 2001, recent research indicates that glacier discharge has increased markedly recent years. Bindschadler (2006) suggests that this is caused by warmer ocean water melting the float ends of glaciers. Also Joughin (2006) and Ekstrom et al. (2006) recognise the increased flow rates of many of Greenland's large glaciers. Additionally, they found an increase in recorded earthquakes caused by glacier movements and the former found an increased calving in the sea. The cause of this increase is not clear, since the period of measurements was relatively short. An enhanced greenhouse effect could be responsible, as well as natural fluctuations. Otto-Bliesner et al (2006) took recent climate change predictions as a boundary for models that relate the global warming to melting of Greenland glaciers. Additionally, they compared this to icefield retreat in the last interglaciation and concluded that sea level rise of about 2.2 to 3.4 meters is to be expected over 3000 years resulting from Greenland icecap melting. Based on a comparison of polar warming of 130,000 years ago Overpeck et al. (2006) conclude that the rate of future melting of the Greenland ice cap and the Antarctic ice sheet might be faster than widely thought, although a maximum from the past found in their analysis would be 1 m/century.

A third process leading to regional sea level rise is related to changes in the thermohaline circulation. Levermann et al. (2005) suggest that a complete collapse of the thermohaline circulation would lead to a rise of sea level in the North Sea of about 0.6 m. It is stressed that a complete collapse is not likely to occur in the coming 2 centuries.

7.1.2 Wind climate

The wind and gales are important for the coast, since they will determine design guidelines of coastal protection works to a high degree, both in terms of wind induced water levels and wind induced waves. A number of aspects are mentioned here:
- the extra wind setup of the sea level generated by gales;
- higher waves (both in terms of period and height) generated by higher wind speeds;
- higher waves penetrating closer to the shore line, because of the higher water levels;
- wind direction: highest set up and waves are generated by north westerly gales;
- wind direction: prevailing conditions determine the location of the shoreline.

Chapter 3 indicates that it is still difficult to predict the possible change in wind climate due to climate change. Nevertheless, these rough estimates do not indicate that major changes are to be expected coming 100 years. On the contrary, even a decline in number of gales has been registered over the last 45 years, although the reason for this is still under investigation (KNMI, 2006)

7.2 Indicators

The impact of climate change on the coastal zone is manifold and covers sectors like agriculture, tourism and urban planning at different timescales and spatial scales. Worldwide vulnerability and impact studies have been carried out that estimate the impact on the coastal zone and develop possible adaptation measures (Bird, 1993; Douglas 2001).

In order to assess the impacts of sea level rise three main indicators were chosen to address the major current socio-economic and ecological concerns in the coastal zone. These are ‘coastal squeeze’, ‘safety against flooding’ and ‘salt-water intrusion’.

7.2.1 Coastal squeeze

In case of a sandy environment sea level rise will cause a retreat of the coastline in landward direction. At the same time, buildings and other types of urbanisation will remain on their location. This results in so called coastal squeeze, where the gradual and natural transition between the water line and dry land infrastructure vanishes and is replaced by hard protection structures like dikes, breakwaters and groynes. This is especially harmful for the inter-tidal area and beaches, which are associated with environmental values and tourism. Figure 7.1 shows the process of coastal squeeze for a coastal plain covered by mangroves. The rising sea level erodes the coast and at the same time, from the landside, agriculture is expanding and/or urbanisation is taking place. This process is stopped in many cases by making a rigid protection measure in the form of a dike.

Coastal squeeze is a process taking place worldwide (Bird, 1993; Douglas 2001). In the Netherlands coastal squeeze is most apparent in estuarine and intertidal environments. Due to deepening of the access channel to the port of Antwerp (which has a comparable effect on the morphology as sea level rise), the intertidal area present in the Western Scheldt estuary is already under pressure (van Dongeren, 1994). The Waddenzee is supposed to be able to cope with rates in sea level rise of 30-60 cm/century (Oost, 2004). Above these rates it is suggested that The Waddenzee will ‘drown’.

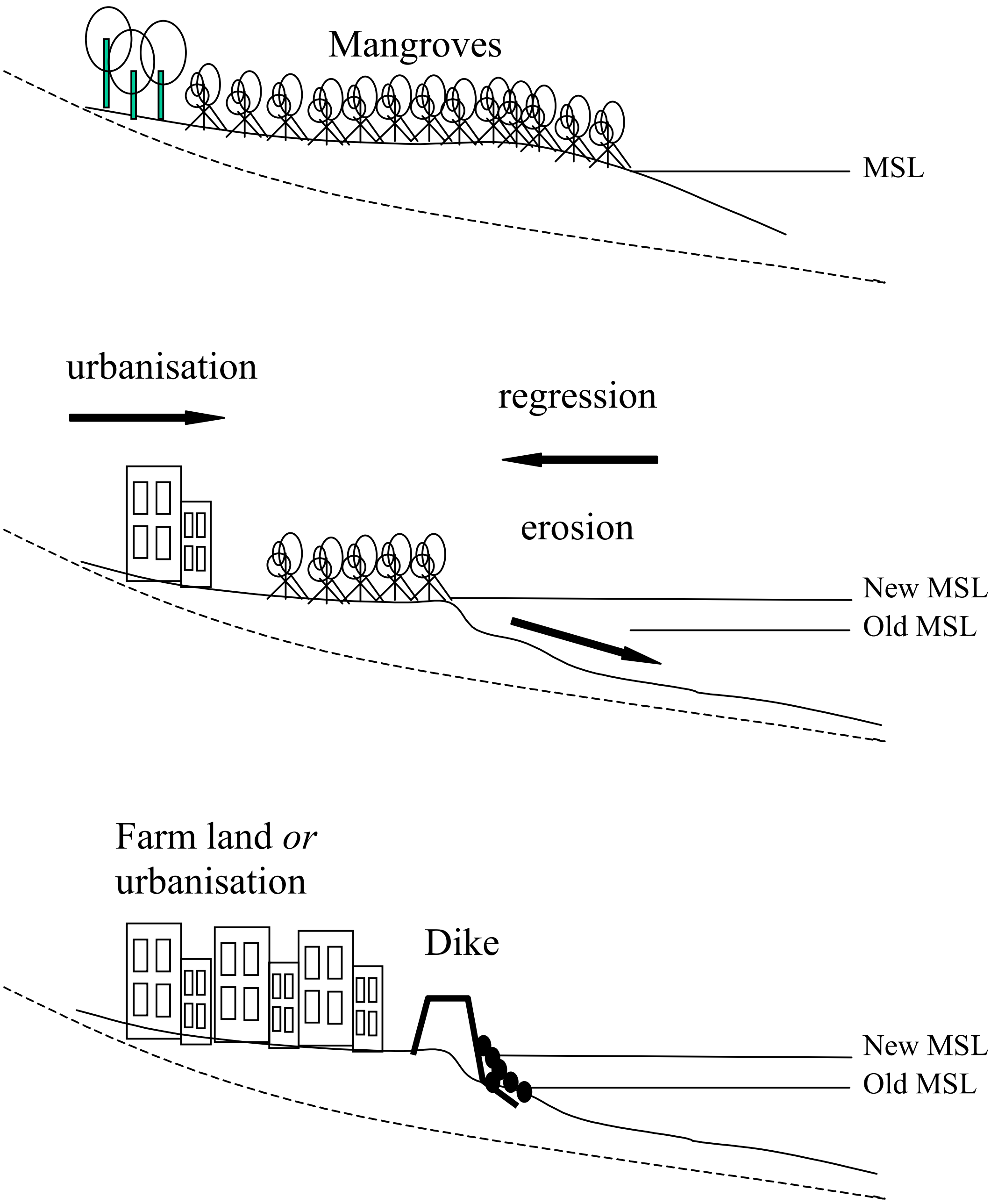

Figure 7.1. The process of coastal squeeze.

7.2.2 Safety against flooding

Safety against flooding is another major concern for coastal plains. It is believed that the majority of the world's population will continue to live in these low lying deltaic areas in the coming decades (Bird, 1993; Douglas 2001). Their risk of flooding can be defined as chance of flooding times the consequences. Both an increased urbanisation (more severe consequences) and a rising sea level (increased chance of flooding) cause the risk of flooding to increase. As a result, both an increased risk and an increased uncertainty will lead to higher costs for coastal protection measures. Design guidelines for coastal protection structures have to deal with uncertainty on the level of sea rise, and with the uncertainty related to changes in the occurrence and intensity of gales.

Based on analysis of a number of major flooding disasters, it is estimated that the number of casualties during a major flood is 1% of the total amount of people directly affected (Jonkman, 2004). For a flooding of the province of Southern Holland with about 3 million inhabitants this would mean a number of 30.000 casualties. This number needs to be considered with utmost care since it assumes that no evacuation could take place and it is only based on historical and rare data. Additionally, local conditions like secondary dikes are not taken into account and evacuation plans, prediction capacity and warning systems have been increasingly improved over the last decades. More detailed analysis (Jonkman & Cappendijk, 2006) shows then a maximum number of about 6000 casualties. The number of casualties heavily depends on (Jonkman & Cappendijk, 2006):

- the predictability of the timing of the flood;
- the number of people present in the flooded area;
- the water velocities causing buildings to collapse;
- the period of the rise in water level;
- the final flood water level.

Wouters (2005) assesses the damage occurring during a flood and subdivides this into:

- direct material damage (real estate, industrial production equipment, stocks)
- direct damage due to production stand still
- indirect damage for economically related areas and industries.

Total damage to the province of South Holland in case of a complete flooding would amount to 290 billion euro, representing the ‘value behind the dikes’. The largest part (95%) is then the direct damage, especially related to private housing (41%). However, secondary dikes reduce the amount of damage considerably. Melisie (2006) argues that the maximum amount of damage does not exceed 37 billion euro.

De Ronde (1990) presents a rough estimation of the costs involved for maintaining the current risk of flooding in case of a sea level rise of 60 cm for the coming century. Applying a correction for the indexation this would result in Table 7.1 (taking 2006 as a starting point). The costs presented do not necessarily have to be made in one year, but may be spread over 10-20 years depending on local urgencies.

Table 7.1. Costs of adaptation works (in billion euro).

Adaptation measure	**60 cm/century sea level rise**	**85 cm/century sea level rise, 10% extra storms and increased river runoff**
Dike improvement works	4.8	9.6
Dune improvement works	0.7	1.4
Upgrade of inhabited and industrial areas in floodplains	1.4	2.8
Improvement works on pumping capacity and sluices	1.4	2.8
Total	8.3	16.6

7.2.3 Salt-water intrusion

Salt-water intrusion from the sea takes place via surface water and groundwater. Salt surface water intrudes in river mouths and estuaries. The length of salt-water intrusion varies during storms and over the tidal period, but may also fluctuate from season to season depending on the river discharge. Salt groundwater will infiltrate when there is a continuous pressure from salt surface water and develops with typical time scales of decades.

The consequences of salt-water intrusion are expressed in terms of degradation of farm land, adaptation of ecological systems, and fresh water availability for drinking water inlets. The higher the rise in sea level, the more the salt water will intrude.

Table 7.2 presents an overview of the yearly averaged chloride concentrations at the drinking water inlet near Ridderkerk in the south-west of the Netherlands for the current situation and the situation in 2050 assuming an average climate scenario. Especially during very salty years (low river discharges) the concentrations will increase. Near Gouda, the expected duration of the period that no water can be taken for agricultural purposes will double to almost a month per year (Jacobs, 2004).

Table 7.2. Yearly averaged chloride concentration (mg/l) near Ridderkerk after Jacobs (2004).

	Current situation	**Situation in 2050 (average climate scenario)**
Weak brackish year	82	82
Brackish year	122	122
Averaged salty year	167	1789
Salty year	178	211
Extremely salty year	344	400

7.3 Adaptation options

Paskoff (2004) addresses potential impacts for the French coasts and concludes that "existing laws and regulations dealing with coastal management are sufficient to address the potential impacts which may affect populations and economic activities in the forthcoming decades as sea level rises". For the Netherlands De Ronde (2004) supports the conclusion that for the coming decades the current physical, administrative and legal system can cope with the implications of sea level rise. No reference was found yet of coastal communities adapting themselves drastically (leaving inhabited areas for example) to increased sea levels, although it is expected that this will occur in the coming decades (for example in highly vulnerable communities on the Maldives). Internet search revealed the ongoing abandonment the horseshoe-shaped Carteret atolls in the Pacific initiated by the Papua New Guinea government.[52] The Carterets are only 1.5 metres high and are projected to be completely uninhabitable by 2015.

The current policy by the Dutch Government is to 'hold the line', which means that the coastline is maintained at its current position. This is done by maintaining hard structures like dikes and by nourishment of beaches and dunes where they are being eroded.
A rising sea level will lead to more and more frequent erosion of the Dutch coast. The following presents a number of possible adaptation options based on a gradually increasing sea level rise and on increasing related socio economic impacts.

- more beach nourishment and increasing the crests of sea dikes;
- allowing occasional flooding of dedicated areas including evacuation plans;
- constructing secondary protection systems more landward and stimulate migration to higher grounds.

In the utmost sense this would mean a withdrawal from the lower areas to higher grounds above the future mean sea level. The adaptation option taken and its timing strongly depend on the rate of sea level rise. Gradually, costs for nourishments and protection maintenance will increase until this measure is not viable anymore from an economic point of view. In that case risk of flooding becomes too high and economic activities will have to move to higher grounds. IVM (2005) presents an overview of possible consequences of a 5 m sea level rise in a century. Although this assumption cannot be verified scientifically and is highly unlikely to occur (ie compare current sea level rise of 2-3 mm per year with the assumed 50 mm per year), the report shows that the costs for adaptation would rise to several percentages of the GNP.

52 http://www.greenpeace.org/international/news/greenlandmelting170206.

Sea level rise results in a disappearance of intertidal areas in the Delta and in the Waddenzee, so that ecologically valuable marshes will vanish. This effect can be counteracted by nourishing the tidal flats at a regular level and in ‘de-poldering’ (agricultural) land so that land is given back to the sea. This strategy is adopted currently in the Western Schelde (not because of sea level rise, but because of deepening of the access channel). Larger systems like the Waddenzee are more vulnerable in the sense that (too) large areas need to be de-poldered. Also nourishments of the tidal flats seem to be too extensive and expensive from an economic point of view.

In the short term, salt-water intrusion may be mitigated by membrane filtering techniques for drinking water inlets and accepting a change of ecosystems from fresh water to salt water based. In the longer term groundwater will be more salt and the system becomes salt water dominated, so that drinking water inlets need to be removed.

7.4 Threshold levels

It is estimated that maintaining the current position of the coastline is technically possible till a sea level of 60 cm above the current position. Above that level, the sea dikes and dunes need to be strengthened to such an extent that the costs are dramatically increasing (De Ronde, 1990; IVM, 2005). Maintenance costs at the current sea level are around 200 million Euro, which equals the maintenance costs for all bicycle paths in the Netherlands. At sea levels higher than 60 cm from the current level, the amounts of sand and clay needed for maintenance are increasingly difficult to withdraw from the natural system. This will increase the costs drastically.
It is difficult to say at what sea level, migration of people becomes a realistic alternative. This strongly depends on the economic viability of the area under protection and the willingness of people to migrate. Usually you need a disaster to get people out of their homes. Until that happens people are inclined to take the risk, especially when the disaster only occurs once every three generations. The threshold value would be then the coastal flooding disaster itself taking place at an increasingly higher probability. On the other hand, it seems likely that our current coastline cannot be maintained with a sea level rise of more than 3 m resulting from the melting of the Greenland Ice Cap as suggested to take place over 3000 years by Otto-Bliesner et al. (2006).
Coastal squeeze and the disappearance of intertidal flats and marshes often result from the policy to maintain a certain position of the coastline for economical reasons under conditions of a rising sea level. Calculations for the Waddenzee indicate that a sea level rise of 30-60 cm per century can be managed by the system and that higher rates will cause the Waddenzee system to gradually change of character with only small areas that are intertidal (Oost, 2004).

7.5 Scientific robustness and gaps in knowledge

It is evident that the sea level is rising. Predictions of absolute levels range from 2 to 4 m depending on the CO_2 emissions taking place and to be reached within 2-3 millennia from now. The coming century the rate of sea level rise is assumed to be in the range from 35 to 85 cm/century (KNMI, 2006). Gaps in knowledge include:

- The process of ice cap melting at Greenland and West Antarctic and their range of uncertainty with respect to absolute sea level and rise in sea level;
- Local variations in sea level rise especially in the North Sea. Current models do not have enough resolution to predict water level at regional seas accurately. KNMI (2006), for example, assumes the worldwide average sea level rise to be representative for the Dutch coast. Although this is roughly verified with worldwide satellite data and measurements from the Dutch coast, sea level rise of the North Sea is not understood in detail;
- Changing wind climate with special emphasis on the impact on the wave climate (both frequency and magnitude);
- Mitigation measures;
- Possible adaptations options including cost estimation, feasibility studies and long-term policy strategies.

8 Climate Impacts on Tourism and Recreation

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8.1 Indicators

Many types of tourism and recreation are strongly influenced by weather and climate. Even if the local climate is not a pull factor in itself, weather conditions often determine the day-to-day activity patterns of tourists and recreationists.

Earlier research has shown that climate change will improve the overall suitability of outdoor recreation and tourism in the Netherlands (e.g. Amelung, 2002; 2004; 2005). The conditions will improve year-round, with the largest increases occurring around the summer season, lengthening the outdoor recreation season. Climate change is less favourable for skating enthusiasts. The frequency of severe frost events will decrease, resulting in decreasing probabilities of the *Elfstedentocht* natural ice skating event.
In view of the above, the three core indicators of the sensitivity of recreation and tourism for climate change refer to:

- the general suitability of the Dutch climate for recreation and tourism purposes:
- indicator: the annual value for the Tourism Climatic Index - TCI (Mieczkowski, 1985);
- the length of the outdoor recreation and tourism season:
- indicator: the number of months for which TCI>70 (‘very good’) ;
- the frequency of the *Elfstedentocht* event:
- indicator: number of potential *Elfstedentocht* events per 100 years (i.e. number of years in which the maximum thickness of the ice is at least 15 cm).

This chapter considers three climate change scenarios: +1, +2, and +3 degrees mean temperature change in the Netherlands. In the absence of scenarios for the Netherlands for the other climate variables that follow these specifications, proxies were constructed as follows:

- Current temperature in the Netherlands (i.e. the case without climate change) is assumed to be the average annual temperature in De Bilt, which is represented by the grid cell containing De Bilt in the CRU set of climate normals for 1961-1990 (New et al., 1999).
- The De Bilt grid cell of the HadCM3 global circulation model[53] forced with a range of SRES[54] scenarios (Johns et al., 2003) emulates the conditions under different levels of temperature change.
  - The A1F-2020s time slice represents the ‘+1 degree’ case;
  - The ‘+2 degree’ case is represented by the average conditions in the B1A-2050s and the B2A-2080s scenarios/time slices;
  - The ‘+3 degree’ case is represented by the average of the B1A-2080s and the A2A-2080s scenarios/time slices.

Table 8.1 lists the use of proxies.

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[53] HadCM3 is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre. The atmospheric component of HadCM3 has 19 levels with a horizontal resolution of 2.5° of latitude by 3.75° of longitude.

[54] The Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Emissions Scenarios (SRES) in 2000. The SRES scenarios have been constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions.

Table 8.1. Proxies used for the +0, +1, +2, +3 degree cases.

Temperature (T) to be emulated	Proxy	Temp. value of proxy
+0 degree (current)	Value of the De Bilt cell in the CRU gridded dataset of climate normals 1961-1990	+0 degree
+1 degree	Value of the De Bilt cell in the HadCM3 model forced with the A1F scenario (2020s)	+0.98 degree
+2 degree	Average value of the De Bilt cell in the HadCM3 model forced with the B1A scenario (2050s) and the B2A scenario (2080s)	+2.00 degree
+3 degree	Average value of the De Bilt cell in the HadCM3 model forced with the B1A scenario (2080s) and the A2A scenario (2080s)	+ 3.01 degree

These proxy data were used for the assessment of the first two indicators, i.e. general suitability, and season length.

8.2 General climatological suitability

The Netherlands' climatological suitability for recreation and tourism purposes can be expressed in terms of the Tourism Climatic Index (TCI), which was developed by Mieczkowski (1985). This index includes temperature, humidity, precipitation, sunshine, and wind as influential factors for tourism. The TCI ranges between 0 and 100, where a score of 100 denotes optimal conditions.

Table 8.2 shows the scores on the TCI index for the current situation, and for temperature changes of 1, 2, and 3 degrees respectively. Figure 8.1 is a graphical representation. Average climatic suitability for tourism in the Netherlands is projected to improve considerably as a result of climate change, with an average of close to 3 TCI points per degree. Temperature changes of up to three degrees can easily be accommodated without a negative effect on mean TCI values.

Table 8.2. Change in the Tourism Climatic Index for the Netherlands according to the +1, +2, +3 degree change scenario.

Scenario	TCI	TCI change
Current situation	48	-
+1 degree	51	3
+2 degree	54	6
+3 degree	56	8

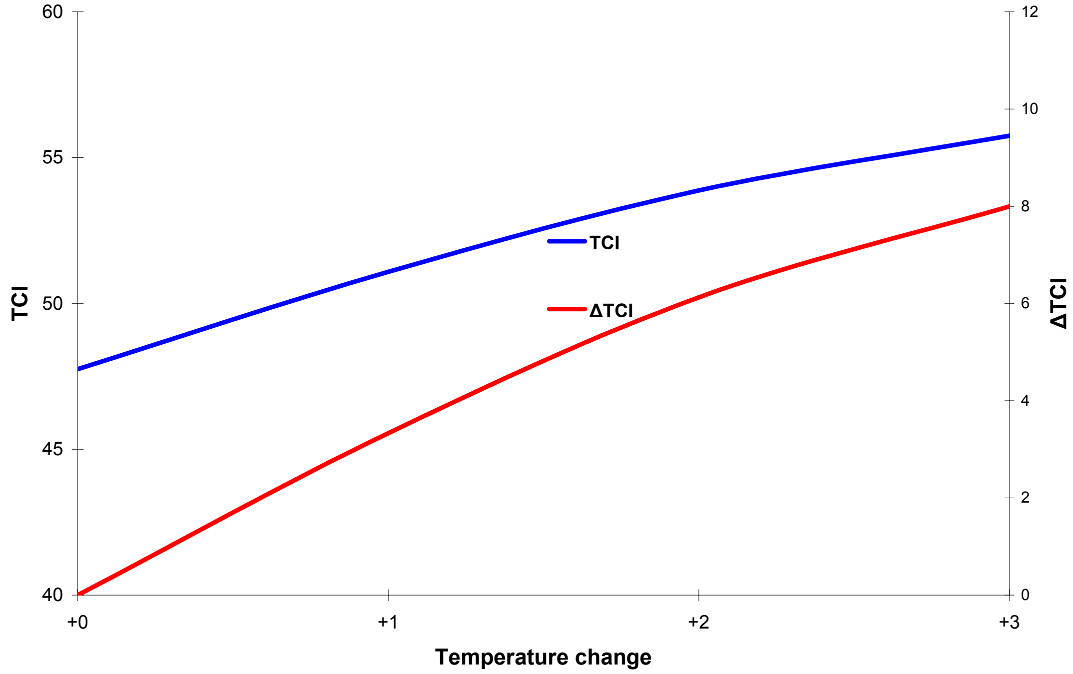

Figure 8.1. Change in the Tourism Climatic Index for the Netherlands according to the +1, +2, +3 degree change scenario.

8.3 Season for tourism and recreation

One of the projected changes for tourism in the Netherlands is the lengthening of the season for which conditions are very good or excellent. A reasonable indicator for the length of the season is the number of months per year for which the Tourism Climatic Index (TCI) value is at least 70.

Table 8.3 gives an overview of the implications of a +1, +2 and +3 degree change for the length of the tourism season in the Netherlands. The results indicated that climate change will not only improve the average suitability, it will also lengthen the tourist season. In fact, the season seems to double, from two months to more than four. Note, however, that these findings are not very precise, because of the temporal resolution of one month.

Table 8.3. Change in the number of months with very good conditions for outdoor tourism and recreation in the Netherlands according to the +1, +2, +3 degree change scenario.

Scenario	**Number of very good months (TCI ≥ 70)**
Current situation	2
+1 degree	3
+2 degree	4
+3 degree	4.5

8.4 Frequency of the *Elfstedentocht* event

With temperatures rising, the probability of having suitable ice conditions for organising an *Elfstedentocht* ice-skating event is decreasing (see also Chapter 3). Whether or not an *Elfstedentocht* event is organised in reality depends on many other issues apart from the thickness of the ice-sheet, such as wind conditions, and water management. That is why the KNMI does not make projections for actual *Elfstedentocht* events, but only for potential events. Such events are defined as those winters in which the maximum thickness of the ice sheet is at least 15 cm. Over the 20th century, the number of such events was 38, while there were only 15 actual *Elfstedentocht* events.

Table 8.4 shows the estimated relationship between temperature change and number of potential *Elfstedentocht* events per century. It is clear that climate change will have an immediate effect on the likelihood of *Elfstedentocht* events, almost cutting the probability in half as a result of one-degree change. Nevertheless, the number of potential *Elfstedentocht* events will reach zero only in cases of very extreme temperature change of more than 8 degrees or so.

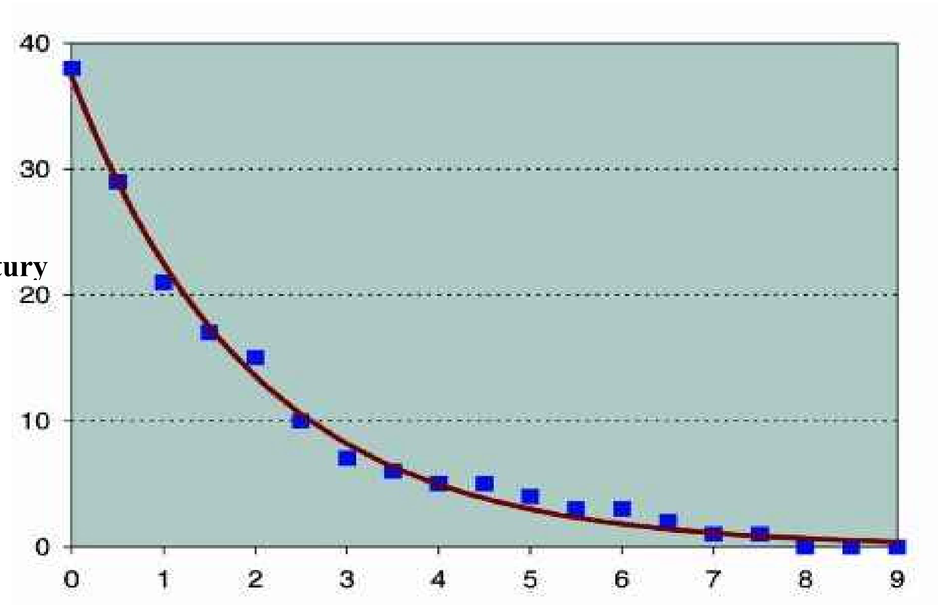

Figure 8.2. The estimated relationship between temperature change and the number of potential Elfstedentocht events per century (source: Theo Brandsma (KNMI).

8.5 Adaptation

In tourism and recreation, most adaptation to climate change is expected to take place autonomously. Tourists will automatically respond to the change in comparative advantage of holiday destinations, and recreationists will continue adapting their behavioural patterns to the current weather conditions. Tour operators will continue to follow the broad trends in demand, perhaps with a few years delay. Planned adaptation is in particular useful for actors that are considering long-term investments. New holiday resorts, for example, generally need to be operational for at least a decade to become profitable. Investments by the public sector in infrastructure and general facilities usually have even longer planning horizons. In today's decision-making on spatial planning, the Dutch government may for example wish to anticipate the additional climate change-induced growth in demand for outdoors activities and beach access.

8.6 Thresholds

Overall, tourism and recreation in the Netherlands are projected to benefit from climate change. Hence, from the perspective of tourism in the Netherlands there are no clear thresholds of ‘unacceptable’ climate change that will likely be passed as a result of climate change. The potentially harmful effect of beach erosion induced by sea level rise can probably be countered by beach nourishment. One of the few major drawbacks of climate change for tourism in the Netherlands is the loss of the *Elfstedentocht* as a periodic cultural and sports events, which is symbolic for the declining opportunities for skating on natural ice. But here, the establishment of a threshold for 'unacceptable' change is very difficult, among other things because of the natural variability in winter conditions.

8.7 Scientific robustness and gaps in knowledge

Despite the obvious links between climate and tourism, scientific knowledge about these links is still scarce. Climate factors are, for example, generally not included in tourist demand models. In recent years, limited validation has been performed of tourism-specific indices such as Mieczkowski's Tourism Climatic Index (TCI), but empiricial proof of their capability of predicting tourist visitation is as yet very limited. Assessments based on these indices therefore continue to have a certain element of speculation. Estimates of the future incidence of *Elfstedentocht* events are based on statistical analysis of past time series, but the actual outcome will to a great extent depend on natural variability.

8.8 Conclusion

Climate change will generally have a positive influence on tourism and recreation in the Netherlands. Overall conditions for outdoors tourism activities (represented by the annual mean Tourism Climatic Index) will improve, and in summer, the period with very good circumstances will lengthen substantially, perhaps even by several months. One of the drawbacks of climate change for tourism and recreation in the Netherlands is the decreasing availability of natural ice in winter that is of sufficient quality for ice-skating. This trend is symbolised by the projected decreasing likelihood of *Elfstedentocht* ice-skating events.

9 Climate Impacts on Agriculture

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9.1 Indicators

The agrarian sector in the Netherlands has seen major changes over the last decades. Not only has the sector developed into an important economic sector but the social, cultural and environmental role of the sector has also changed dramatically.

Intensification, concentration and specialization, as a response to agricultural policies, characterize the pathway of economic success. But this has come at environmental and social costs. Problems related to pollution, animal health, nature, a 'liveable' countryside and human well-being are high on the research and policy agendas. In some areas the sector has undergone a shift away from primary production and moved to multifunctional land use combining e.g. production with nature and recreation. These new functions of agriculture are however difficult to capitalize. Agriculture developed responding to environmental signals, policy signals, market signals and technological developments.

More recently the sector is confronted with problems related to the liberalization of producer and consumer markets. In order to survive in a highly dynamic and competitive environment the agrarian sector has to develop flexible competitive systems. This requires not only transitions within the sector but also institutional and legal settings (e.g. legislation, EU regulations) and organization of the value chain that allow for change.

That climate change will have an impact of agriculture in the Netherlands is clear but whether or when its effects are a major threat to the sector is not clear, as responding to weather changes is an intrinsic part of agriculture.

Clearly climate change and climate variability will have an impact on agriculture. For example the drought of 2003 resulted in drastic changes in agricultural output over Europe. Impacts of climate change are evident via changes in crop productivity, economic return, quality of product, damage to crops and buildings. Most studies however focus on changes in crop productivity related to gradual change.

Several papers (e.g. Harrison and Butterfield, 1996; Nonhebel, 1996; Downing et al., 1999; IPCC, 2001, Olesen & Bindi, 2002; Wolf & van Oijen, 2003) conclude that in northern areas of Europe climate change may produce positive effects on agriculture through introduction of new crop species and varieties, higher crop production and expansion of suitable areas for crop cultivation. The disadvantages may be an increase in the need for plant protection, the risk of nutrient leaching and the turnover of soil organic matter. In southern areas the disadvantages will predominate, de facto given extra stimuli to agriculture in the northern areas. Olesen and Bindi (2002) further conclude that "The possible increase in water shortage and extreme weather events may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops. These effects may reinforce the current trends of intensification of agriculture in northern and Western Europe and extensification in the Mediterranean and south-eastern parts of Europe." The same reasoning would hold on a global scale, with the worst impacts expected in tropical regions temperate regions may have to reinvest in increasing food production to keep up with increased food demand in mainly the tropical regions.

More recently, EEA (2004) presented an inventory of the impacts of climate change on Europe and presented the following key findings for agriculture:

- The yields per hectare of all cash crops have continuously increased in Europe in the past 40 years due to technological progress, while climate change has had a minor influence.
- Agriculture in most parts of Europe, particularly in mid and northern Europe, is expected to potentially benefit from increasing CO_2 concentrations and rising temperatures.
- The cultivated area could be expanded northwards.
- In some parts of southern Europe, agriculture may be threatened by climate change due to increased water stress.
- During the heat wave in 2003, many southern European countries suffered drops in yield of up to 30%, while some northern European countries profited from higher temperatures and lower rainfall.
- Bad harvests could become more common due to an increase in the frequency of extreme weather events (droughts, floods, storms, hail), and pests and diseases.

Results on changes in productivity are mainly based on crop modelling. Crop models are useful tool in understanding processes and interactions between crop-soil-atmosphere and management but the results may not related very well to actual production levels as these depend not only on bio-physical factors but are also related to policy and market signals and technological developments.

How agrarian systems respond to extremes is less well understood, but recent examples of damage related to flooding, drought, hail and storms reveal that impacts of extreme events are large. In the following sections we will look at several climate factors and try to identify critical thresholds in relation to crop production and damage in relation to extreme events.

9.2 Crop productivity

The impact of changes in temperature and temperature variability on crop productivity is complex. Changes in the mean and variability of temperature can affect crop processes but not necessarily the same processes. Photosynthesis and respiration show continuous and mainly nonlinear responses as rates of development and progression though live cycles more often show linear responses (Porter & Semenov, 2005). Different processes have different optimal and threshold temperature values, for c3 crops (e.g. wheat) the optimal range for photosynthesis is 20–32°C and respiration shows a linear increase from 15–40°C followed by a rapid decline (Porter & Semenov, 2005). Higher temperatures will result in a faster development and earlier maturation of crops and with lower yields. The thresholds may also differ per development stage moreover short-term extreme temperatures and temperature variability is an important determining factor in crop yield (Porter & Gawith, 1999; Challinor et al., 2005).

Porter and Semenov (2005) present temperature thresholds for wheat, the lethal limits are around -17.2 (1.2) and +47.5 (0.5) °C. During the grain filling period the minimum, maximum and optimal temperature were found to be 9.2 (1.5), 35.4 (2.0) and 20.7(1.4) °C for anthesis these temperature are 9.5 (0.1), 31.0 and 21.0 (1.7) °C. A general observation is that the lethal limits are wide and temperature ranges for the reproductive phases are narrower. In any case a 2°C temperature increase will not have a dramatic effect on production in the Netherlands.

Water is a crucial factor in crop production and changes in precipitation deficit can affect crop productivity. If and when drought becomes a problem is not clear. This will depend on irrigation possibilities, water quality and the impacts in other regions in Europe. Local differences within the Netherlands however do exist. The lower areas are less vulnerable to drought than the higher sandy areas.

Ewert et al. (2005) developed a simple static approach to estimate future changes in the productivity of food crops in Europe. They found that changes in crop productivity, over the period 1961 – 1990, were strongest related to technology development and effects of climate change were relatively small. Annual changes during that period were more pronounced for cereals such as wheat (*Triticum aestivum*) (1.74%) and maize (*Zea mays*) (1.89%) than for root crops such as potatoes (*Solanum tuberosum*) (1.34%) and sugar beet (*Beta vulgaris*) (1.1%).

As there is still scope for some further improvement in crop productivity e.g. via changed harvest index, environmental adaptation and genetic engineering (Evans, 1997) and progress in management there is no indication that technological development will stop. Ewert et al. (2005) estimated the increase in crop productivity till 2080 to range between 25% and 163%. The contribution of technological development of this increase was between 20% and 143%. It seems that agrarian productivity in Europe is hardly affected by gradual changes in climate. The sector is resilient and responds strongly to policy and market changes and hardly to changes in climate.

9.3 Damage from extreme weather events

Perhaps more important is the damage inflicted on agriculture via extreme weather events. Weather extremes not only affect quantity and quality of crop production but also may result in damage to buildings. Insurance is the normal strategy to deal with the damage. But with increasing frequency and strength of extremes costs and damages could turn out to be unbearable. For the Netherlands only a few studies related to issue are available most of those are carried out by IRMA (Institute for Risk Management in Agriculture, Wageningen University and Research Centre).

Farmers are partly compensated for damage from extreme weather events via a disaster relief programs such as: The ‘Contribution at Disasters and Severe Accidents Act’ and the ‘Contribution at Disasters and Severe Accidents Decree’ (van Asseldonk et al. 2000) allow compensation for the events such as flooding as a result of dike bursts. Besides these programs in special cases a Royal Decree can be issued. As a result, political pressure by stakeholders can encourage and trigger government financial assistance via free disaster relief programs (van Asseldonk et al., 2002). The frameworks not only compensate risks that are in the public arena but also include compensation of private risks related to extreme weather events (e.g. frost and drought risks).

In the last 25 years, producers claimed, on average, Dfl. 29.5 million (approx. 13.5 mEuro) per year. The initiated relief programs included the perils drought, frost and precipitation. The compensated losses were lower since the relief programs incorporated a substantial deductible. The historic overview shows that Dutch producers were (partly) compensated in the event of widespread losses. More local losses as a result of adverse weather conditions, which could be a catastrophic event at the producer level, were not eligible for disaster relief (van Asseldonk et al, 2000).

Van Asseldonk et al. (2002) present a short overview of how the frameworks are implemented: “The initiated relief programs included the perils caused by drought, frost, and precipitation. During a severe drought in 1976, approximately Euro 255 million was claimed by producers, of which Euro 132 million was indemnified by the Dutch government. The estimated frequency of such droughts was once per 30 years. As a result of a severe frost period in 1985, an estimated loss in Dutch agriculture of Euro 45 million occurred which was partly compensated for. The estimated frequency of the frost period was once in 25 years. In 1998, two severe rainfall events in different regions resulted in major crop losses. The projected losses for the two regions, with at least 100 mm rainfall in 48 hours, were estimated to be Euro 210 million and Euro 115 million. With a deductible of Euro 4500 per farm, compensation of Euro 125 million and Euro 82 million were paid, respectively. The estimated frequency of the two events was once per 110 years and once per 125 years. In other regions in which the rainfall criteria did not trigger disaster payments, an alternative relief program was launched. In this latter program, a 30% deductible of the total production value of each cultivated crop was accounted for. The amount indemnified was Euro 42 million, while the estimated total loss to farmers was Euro 118 million. The historic overview shows that Dutch producers have been partly compensated in the event of widespread losses by means of disaster relief programs. More local losses as a result of adverse weather conditions, which could be a catastrophic event for a few individual producers, were not considered eligible for disaster relief.”

Related to the increased frequency of extreme events and increased costs new frameworks are developed to abandon the ad hoc basis via a disaster relief program and formulate structural long term private market solution. This has resulted in a new insurance for water related damages Aquapol, which emerged from cooperation between the government, farmer's organizations, an insurance company and a bank.

For policy-holders issues related to the spatial risk basis remain a concern (van Asseldonk, 2003). For both policy-holders and insurance companies it is unclear what the effects of climate change and changes in climate variability and extremes will mean. Langeveld et al. (2005) present a modelling methodology to evaluate vulnerability and adaptation strategies related to extreme events. Field level adaptations to extreme wet conditions were evaluated for potato production in the Netherlands using a crop simulation model. The focus was to design a methodology to address vulnerability and adaptation strategies. Timely adaptation will be essential. Existing strategies can be discerned between actors (farmers, sector, government, and insurers) and level of action (farm, region, sectoral, national). Langeveld et al. (2005) explored three field level adaptation strategies delayed planting; improving irrigation; improving drainage. The results suggest that costs for coping will varied between 5-20% for delayed planting and 15-40% for increased irrigation.

9.4 Commodity prices

The food and luxury food industry in the Netherlands is processing more and more raw materials from foreign countries. The importance of foreign suppliers to the food and luxury food industry in the Netherlands is increasing. Besides producers of products for the food and luxury food industry farmers in the Netherlands are also customers of imported raw materials. The agricultural sector in the Netherlands has a large import of agricultural products both of raw products for processing in the Netherlands as well as of food products for direct consumption (Bijman et al., 2003). The largest size (in terms of Euros) of import from countries outside the European Union is constituted of the following agricultural products: oil-bearing seeds, fodder plants (mainly soybeans), (tropical) fruit, nuts, spices, margarine, oils, coffee, tea and cacao beans (WUR, 2005).

These products are coming from different regions of the world: the United States of America, South America, Africa, South East Asia (Wijnands & Silvis, 2000; LEI, 2005). The price of these imported agricultural products is an important factor of influence on the production costs and finally the price of food (e.g. meat). Several studies (Rosenzweig & Parry, 1994; Fischer et al., 1994; Reilly et al., 1994; Fischer et al., 2002; Parry et al., 2004; Parry et al., 2005) expect climate change causing changes in world market prices for cereals. Reduced production due to climate change, leads to increases in cereal prices by as much as 17% by the 2080s till even by about 45% depending on the future climate conditions predicted (Parry et al, 2005). Furthermore simulations with different levels of adaptation suggest heavier adaptations are required to mitigate the negative effects of climate change such as changes in cereal prices: large shifts in planting date, increased fertilizer application, development of new varieties and installation of irrigation systems. According to Parry et al. (2005) the potential for adaptation is greater in more developed economies. Assuming full trade liberalization in agriculture by 2020 provides for a slight reduction of cereal price increases from what would occur without full trade liberalization. And estimations under a lower economic growth scenario (ranging from 2.7% per year in 1980-2000 to 1.0% in 2040-2060) results in higher cereal prices (10%). Making statements on the effects of changes in commodity prices for the import in the Netherlands is difficult because above mentioned studies did not focus on the specific agricultural products imported by the farmers and the food and luxury food industry in the Netherlands. Further the 'danger' of climate change on the import of agricultural products by the Netherlands is determined by the regions and particular the countries from which the Netherlands is importing the products, namely US, Brazil, Argentina, Cuba, Israel, West Africa, Vietnam and Indonesia. Considering the impact of climate change on the cereal production in those countries with adaptation, and the impact on global cereal prices, one can ask oneself if that will have significant impact on the import trade with the Netherlands. On the other side the Netherlands as an exporting country can profit of the estimated increase of world market prices of agricultural products.

9.5 Adaptation

Agricultural systems have developed numerous strategies for coping with changing environmental conditions. The most obvious strategy is found in the selection of crop and cultivar or animal species, irrigation and drainage are other examples. In a way adaptation in response to environmental change is part of the development of agriculture.

9.6 Thresholds

The general picture for the Netherlands indicates that financial resources, technology and know-how are sufficient to cope with gradual climate change. The 2°C policy target will not pose problems to crop productivity. Changes in water availability could in some areas lead to drought stress and result in production losses. Whether loss of productivity will also result in lower economic returns will strongly depend on impacts in other parts of the globe. No clear thresholds could be identified.

Increased damage related to changes in extreme weather events could however have a devastating effect on the competitiveness of agriculture in the Netherlands. Thresholds related to extremes are, however, unknown.

No thresholds are found in (international) scientific literature about the relationship between the level of world market prices of agricultural products, due to climate changes, and impacts on trade flows out of third countries into the Netherlands, especially towards farmers and the food industry in the Netherlands.

9.7 Scientific robustness and gaps in knowledge

Not enough information is available concerning impacts of changes in world market prices of agricultural products on the import of agricultural products (for instance fodder plants) for farmers and food industry in the Netherlands. Considered impacts are based on speculation of experts.

10 Conclusions and recommendations

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10.1 Introduction

In order to understand the urgency with which climate change needs to be controlled, it is important to realise the extent to which climate change can become dangerous for countries. The key question that this report addressed is thus: How can Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) be elaborated into quantitative indicators for climate change control? Other relevant questions are:

- What operational criteria could be developed to indicate dangerous and non-dangerous levels of anthropogenic interference with the climate system?
- What indicators can be selected that are both politically relevant and publicly comprehensible and appealing, and that can be scientifically substantiated (attributable to climate change, reliable/valid, measurable, predictable)?
- How can different indicators be integrated?

10.2 Methodology

This report is not the result of new research. It is instead an assessment project, which means it merely assesses the existing scientific information available at this point of time. In other words, this report has a limited methodology. It should be noted, however, that the research builds further on the earlier completed assessment of when climate change becomes dangerous for the Netherlands. Three points about this assessment can be noted here. First, although some scientists see a definition of dangerous climate change as a futile exercise, we see it as a worthwhile endeavour, despite its shortcomings. Second, through identifying indicators, it is possible to work backwards through identifying threshold levels, temperature changes and concentration levels, and finally define acceptable emission levels. Third, although we build further on the results of a limited participatory integrated assessment, carried out in the previous round of a related project, this project merely updated the information and tested out the results at a national workshop.

10.3 Literature review on assessing dangerous climate change

Chapter 2 assessed a large part of the literature on dangerous climate change. It reveals a number of key issues.

- What is inherently clear is that defining dangerous climate change is something that is highly controversial. Many scientists deny that there is an objective method to define dangerous climate change and hence argue that the effort to do so is futile. Others argue that given the high degree of danger inherent in climate change, it is absolutely vital that efforts are made to define what constitutes dangerous climate change.
- Although there are a number of different methods used to identify dangerous climate change, most seek to only look at some part of the entire chain from impact through concentrations to emissions to the perception of the problem. Most authors identify indicators related to certain climate impacts but the identification of thresholds is difficult, as most impacts gradually increase with increasing temperatures. In such a case there are no clear thresholds. There is also considerable overlap between the indicators identified in the literature. Most articles focus on one or more indicators.
- Each discipline looks at danger differently and what is considered dangerous also differs between one person and another. In this report we try to indicate the reasons that can be given to consider a certain climate change dangerous or not.

- In the selection and assessment of indicators there are two kinds of risks. One, the choice of scale to determine risk is mainly national. At least most countries and researchers are studying this at national level. Only systemic impacts (i.e. large-scale events) are evaluated at a global level; almost all other impacts are seen purely from a national or local perspective. This may imply that impacts in other countries and regions are not taken into account to the fullest extent. The other issue is that there is a tendency to argue that since such risks are gradual, adaptation can play a major role. However, taking adaptation into account is not an easy exercise; and literature on adaptation demonstrates the numerous problems involved.
- Finally, several authors argue that a 2ºC rise in temperature (or 400 ppmv CO_2-eq. Concentration level) from pre-industrial levels is the level at which dangerous climate change can set in because of the potential impacts of low-probability high-impact events. However, for many sectors and for abrupt and extreme events it is not clear if specific thresholds can be specified. Gradual change of our climate and gradual change of related impacts without a clear threshold temperature is more common. Therefore ultimately, the discussion on what is dangerous climate change, or in other words what are we willing to accepted as a society, will be determined in the political arena, on the basis of much more than only the scientific information.

10.4 Towards an updated Netherlands' perspective on dangerous climate change

An assessment of the state of the science on the climate system shows that given the multiple scales at which the climate change system functions, and the multiple positive and negative feedback loops, the future evolution of (regional) climate is subject to many uncertainties. These include the uncertainties regarding the development of anthropogenic activities, and related emissions of greenhouse gases and changes in land use; and limited understanding of the complex climate system; its inherent internal variability and its response to changes in concentrations of greenhouse gasses and land use changes. Nevertheless, the Royal Meteorological Institute for the Netherlands formulated four scenarios for the Netherlands. It is considered most likely that our future climate will develop between these four 'corner points'.

In general, projected changes have an increasing uncertainty when following the series of variables from temperature via sea level rise, precipitation and wind. Wintertime precipitation is more certain than changes in precipitation in summer. The mean changes are more certain than changes in extremes (events that occur once per 10 year or even less, and also 'abrupt' changes). This chain is partly dictated by the complexity of the underlying physical processes.

The gaps in knowledge include the circulation response of increased greenhouse gas concentrations; the dynamics of glaciers and large ice sheets; changes in precipitation at high latitudes; and the role of land surface interactions including snow and soil water.

10.5 Indicators of relevance to the Netherlands situation

The previous project identified 23 indicators on the basis of available literature and a workshop with a limited number of stakeholders. The indicators were chosen to be representative and scientifically sound for the assessment of climate change impacts in the Netherlands. Since the discussion on the assessment of the term 'dangerous' is closely related to public perceptions, an important criterion for the selection of the indicators was the appealing character of the indicator. Furthermore, it was decided not to present an extensive list of indicators, in order to keep the discussion transparent. In this project, the project team revisited the indicators on the basis of the new information available and concluded that the key indicators could be clustered along six key sectors for the Netherlands – namely fresh water, ecosystems, health, coastal zones, tourism and recreation, and agriculture. The impacts on industry (e.g. cooling water for energy generation) were captured under the above headings. It was also decided not to study economic impacts separately from the sectors, since that would lead to double counting. In addition, the team decided to include the threats posed by extreme events and abrupt events separately. Finally, during the stakeholder workshop in the previous project, some global indicators were seen also as critical to the Dutch cosmopolitan identity. Although these were not specifically investigated, it was decided to keep a generic category of international solidarity as an indicator.

10.5.1 Impacts on fresh water may require substantial adaptation

Four indicators in the area of fresh water were selected for this study, of which two are related to river discharge and two to precipitation. For river discharge these are design discharge and low flow discharge, as an indicator for navigation. For precipitation, these are the 10-day precipitation sum as an indication for waterlogging, and the precipitation deficit. The indicators stand for instance for the safety against flooding, access to and availability of clean water, navigation, and cooling water. The research indicated that due to climate change the river discharge is expected to increase in the winter and decrease in the summer. There is a likelihood that the regional water and the urban drainage system will have greater waterlogging problems, due to increasing precipitation. The Netherlands already experiences a minor water deficit in the summer months, and depending on the climate scenario the problems in the local system increase. Larger water deficits may result in serious problems for e.g. agriculture, ecosystems, etc. Due to lower river discharge and sea level rise it will be more difficult to discharge the river water in the North Sea. As a consequence there will be more salt-water intrusion, which threatens the fresh water supply for the regional water system and the drinking water supply. Due to the lower discharge of the Rhine in the summer, navigation will be negatively affected in summer months. Problems with cooling water for power plants will increase, because the water temperature will increase due the lower discharge and the increasing temperature. In order to reduce the risk of climate change the water system will need to be adapted to a climate change based on the +1°C temperature increase for 2050. In the case of flooding the adaptations consists of retaining and storing of water. However, there are also problems related to, for example, cooling water, where the adaptation has to be made by the sector itself. The above information is partly based on existing laws and policies, and partly on well-established scientific information, while some of the extrapolation is partly based on reasoning.

10.5.2 Ecosystems may not easily adapt

Indicators were selected for five elements of ecosystems that may be affected at a global, regional and local level. The elements include phenology, plants and vegetation, mammals, birds, and marine species. Indicators for each of these elements were assessed and these revealed that considerable impacts are already occurring now. Many show that species and ecosystems are able to cope with observed levels of climate change but some are detrimental. Beyond a 1-2°C warming, these detrimental impacts are expected to start to dominate and beyond a 2°C risks rapidly increase. This could become a major threat to biodiversity. The assessment of the recent scientific literature indicates that the Third Assessment Report of IPCC underestimated the climate change impacts on species and ecosystems. The terrestrial carbon balance would likely shift after a few decades from a sink into a source. This has serious consequences for managing atmospheric concentrations. There will be rapid phenological responses of plants and animals, widespread shifts in species geographic ranges, and changes in structure and composition of most ecosystems (not only in the boreal zone as previously stressed). There is now growing evidence for a high vulnerability of a considerable fraction of species becoming committed to extinction than previously assessed. Changes in disturbance and other stresses such as fires, invasive species and pollution are likely to exacerbate climate change impacts.

Endemic species (i.e. unique species confined to a small area) are very sensitive to climate change, resulting in clear impacts on biodiversity and biodiversity hotspots. The most sensitive ecosystems are coral reefs, Arctic systems, mountains, Mediterranean systems and savannas.

In most cases, species persistence requires migration rates that exceed their natural adaptive capacity. These effects, combined with landscape fragmentation and pollution, limit natural adaptation, and increase their risk of extinction during this century. Marine ecosystems and species appear more able to shift range rapidly than many terrestrial species. All these impacts will lead to detrimental changes in ecosystem services. Impacts on sustainable development and livelihoods of people depending on the ecosystems remain, however, difficult to estimate.

The TAR already established in 2001 that beyond 2ºC global mean temperature increase compared to the pre-industrial level risks for negative impacts on species and ecosystems rapidly increased. This analysis shows that this assessment was too conservative. Risks for impacts on many local and regional species and ecosystems already rapidly increase beyond 1ºC global mean warming and are also not negligible at lower temperature increases.

To limit the risks for impact of climate change on ecosystems two approaches have to be taken. First, climate change has to be limited by limiting and reducing greenhouse gas emissions. This seems economically and technologically feasible. Second, the resilience of species and ecosystems has to be increased. One of the most effective strategies to achieve this is to reduce other stresses on species and ecosystems and enhance conservation efforts. However, the cascade of uncertainties from climate change projections through species to ecosystem responses remains a significant barrier to develop coherent and detailed regional policy planning.

10.5.3 Impacts on health

In the health sector, three indicators were chosen. These include increased mortality as a result of heat waves, increased risk of Lyme disease, and an increased risk of pollen allergies. Past heat waves in the Netherlands have resulted in an excess mortality of 38.9 excess deaths (12.8%) per heat wave day. However, part of the excess mortality during heat waves must be viewed as ‘only a slight forward displacement of deaths’. The other part of the excess mortality, however, relates to avoidable deaths and substantial loss of life. The most vulnerable to heat waves are senior citizens, persons with cardiovascular or respiratory disease, and young children. The view that climate change will have an impact on heat wave mortality is well established. Climate-change-induced heat wave mortality might become unacceptable under various assumptions regarding adaptation capacity and ‘forward displacement’.

The expectation that climate change has an impact on Lyme is well established, although more quantitative research is required. Tick densities are positively correlated with human Lyme disease. With less harsh winters, it is expected that tick survival, and, consequently, tick densities will increase. In addition, a significant prolongation of the tick-season is expected. If climate change would result in a (possible) 1% increase in disease incidence, the acceptable lifetime risk on morbidity – induced by climate change – might be exceeded.

Weather conditions affect the timing/duration of the pollen season, the quantity of pollen produced and the geographic distribution of flowering plants. However, the impact of climate change on allergic disorders is uncertain and there is a need to better understand this relationship between the changing climate and allergic disorders.

A wide range of adaptation options are possible which include legislative, technical, educational and behavioural changes that could enhance the ability of humans to overcome these risks. What is clear is that risks increase as temperature rises, but that adaptation may reduce these risks somewhat. More research on adaptive capacity is required.

10.5.4 Impacts on coastal zones will require substantial investment and adaptation

Having a long history of battling sea level rise, the Netherlands is well prepared to deal with the three indicators related to coastal zones.

- The first indicator is coastal squeeze, where a rising sea level leads to a shrinking of the coastal zones: Dune type of environments are thus gradually changed into more hard protection measures like dike systems.
- The second indicator is the risk of flooding. In order to maintain the current risk standards, major protection measures are needed against rising costs in case of higher sea levels. The same holds for the frequency and magnitude of exponentially rising costs in case of higher sea levels. Additionally a rising sea level brings with it a higher uncertainty. The reason for this is that the behaviour of the North Sea system induced by higher sea levels is not known from history. The same holds for the frequency and magnitude of extreme events like storms.
- Salt-water intrusion is the third indicator. Higher sea levels will cause salt surface water and groundwater to intrude further inland, impacting the freshwater supply and ecosystems. While in the short-term salt water intrusion can be prevented through membrane filtering techniques, in the longer-term, this may be difficult to deal with and drinking water inlets need to be moved more upstream.

10.5.5 Impacts on tourism and recreation may be beneficial

Not all the news is bad, as the story about tourism and recreation indicates. Climate change will generally have a positive influence on tourism and recreation in the Netherlands. Overall conditions for outdoor tourism activities (represented by the annual mean Tourism Climatic Index) will improve, and in summer, the period with very good circumstances will lengthen substantially, perhaps even by several months. One of the drawbacks of climate change for tourism and recreation in the Netherlands is the decreasing availability of natural ice in winter that is of sufficient quality for ice-skating. This trend is symbolised by the projected decreasing likelihood of the *Elfstedentocht* ice-skating events.

10.5.6 Impacts on agriculture

Three indicators were selected to represent the potential impacts on agriculture. These include a change in crop productivity, damage from extreme weather events and changes in commodity prices. Farmers are used to dealing with weather variability, a two degree temperature increase over the next century will not have a severe impact on the sector, as farmers will adapt. The direction and speed of development in the sector are strongly determined by economic and technological drivers. However, farming systems are vulnerable to extreme weather events and salt water intrusion. To which extent insurance remains a feasible option is unclear.

As the effects of climate for the Netherlands are relatively low when compared to other regions in Europe (e.g. southern Europe) current trends of intensification of agriculture in northern and Western Europe and extensification in the Mediterranean and south-eastern parts of Europe could be reinforced by climate change. These developments could have a positive effect on the competitiveness of agriculture in the Netherlands.

As the Netherlands is strongly engaged in commodity trade, impacts of climate change in other countries may raise the price of commodities affecting the market situation. In globalising and liberalising markets it will most likely result in shifts in production centres.

10.5.7 Extreme events

There is much speculation in the literature about the increased risk of extreme events following climate change. On the basis of the most recent analyses of KNMI it can be concluded that as a result of climate change:

- Temperatures, and related the chance of heat waves, will continue to increase;
- Precipitation in winter will increase, resulting in higher river discharges. In summer precipitation may increase slightly, or decrease clearly, resulting in hardly any change in river

discharges or clear decrease. The intensity of extreme precipitation will increase in winter and summer;
- There is no indication that the intensity of gales in the Netherlands will increase clearly as a result of climate change.

Despite the small risk of extreme events in the Netherlands occurring, the financial and socio-economic consequences could be enormous. The possible impacts of these extreme events have been included in the sectoral indicators, e.g. agricultural damage from drought, increase mortality due to heat waves, and floods.

10.5.8 Impacts of low risk high impact abrupt events could be substantial and need to be avoided

A key problem is the potential of low-risk high-impact events that could change the shape of the climate – and the world – completely. Examples of low risk - high impact events are melting of large ice caps (Greenland, Antarctica), collapse of the thermohaline circulation, excessive release of carbon by melting permafrost etc. Most literature considers it unlikely that these events will occur in the 21st century at the temperature projections of the IPCC (+1.4 up to 5.8°C compared to 1990). Although, most consider the risk to increase with increasing temperatures (but still unlikely during the 21st century), no clear threshold can be given.

10.5.9 North-South solidarity

While many of the risks to the Netherlands may be manageable if the rate of change does not exceed certain thresholds, small island states and developing countries with coastal zones, and mountain zones are likely to be extremely vulnerable to a global mean temperature rise. There is very little literature to assess when solidarity thresholds can be crossed, but we did not consider that reason enough to not even mention this point.

10.6 Indicators and threshold levels

The following table attempts to sum up the information provided above in a comparative and simple manner. It indicates the type of indicator; the name of the indicator; and a brief description of the impacts for the Netherlands. It then uses a simple code to indicate how serious the impact can be; where a negative sign stands for a negative impact, and a positive sign for a positive impact. 0 stands for neutral. Where there will be autonomous adaptation – we indicate that with “aa”. Where there needs to be proactive adaptation, we indicate that with ‘pa’. Where systems become endangered, we show that through “ed”. The term ‘na’ indicates not available. For a more extensive and nuanced description, see the various Chapters.

Table 10.1. Indicators and impacts relevant for the Netherlands at different mean global temperature rise compared to pre-industrial level (with and without adaptation).

Type	**Indicator**	**Description**	**+1º C**	**+2º C**	**+3º C**
Sectoral					
Fresh water	River discharge: design discharge	Higher winter discharge; increase of the design discharge	-	-	--
	River discharge: low flow	During the summer lower discharge, causing problems for navigations and power plants (shortage of cooling water), salt water intrusion	-	-	--
	Precipitation: 10-day precipitation sum	Waterlogging regional system; possible local water excess		-	--
	Precipitation deficit	Water shortage in the regional system		-	--
Ecosystem	Trees and plants	Physiology, phenology and distribution changes	-	-- Ed	--- Ed
	Mammals	Impacts on mammals	na	na	na
	Birds	Impacts on birds	-	--Ed	---Ed
	Marine species	Obvious in the North Sea, but also elsewhere in the oceans.	-	Ed	Ed
Health	Heat wave mortality	Mortality that can be attributed to heat waves	- aa/pa	-- pa	--- pa
	Lyme disease	Infectious disease spread by ticks	- pa	--- pa	--- pa
	Allergies	Increase in allergies because of pollinating season.	- na	-- na	-- na
Coastal zone	Coastal squeeze	Area between sea and coast shrinks	-	--ed	---ed
	Flooding	Increased risk of coastal flooding	0	pa	pa
	Salt water intrusion	Increased salt water intrusion	-	-- pa	--- pa
Tourism	Tourism climatic index	Tourism becomes attractive	+	++	+++
	Length of the outdoor recreation and tourism season	Recreation months increases	+	++	+++
	Frequency of the 11 city skating event	Frequency decreases	-	--	---
Agriculture	Crop productivity	Adapts to change in weather	0	-/+	-/+
	Damage from extreme weather events	Increase in magnitude and frequency	0	na	na
	Commodity prices	Price changes on world market → switching to other suppliers (countries), composition food products changes; could benefit the Netherlands	0	0/+	0/+
Systemic					
Extreme events	Frequency and intensity may increase		0/-	0/-	0/-
Abrupt events	WAIS, GIS could melt		na	na	na
Solidarity					
International solidarity		Water and food access may decrease; impacts of SLR on low-lying countries	0/-	-	--

N.B. The temperature rise is for global mean temperature rise since pre-industrial levels.

10.7 Communicating the information

The potential impacts of climate change on the Netherlands can be visualised as shown in the following figure. This figure updates and replaces the earlier figure entitled ‘Perceived reasons for concern in the Netherlands’ (Gupta & van Asselt (eds.), 2004). The following figure includes impacts on six sectors; irreversible systemic impacts; and international impacts that may concern the Dutch citizen. Text in bold indicates whether there is substantial literature pointing in a specific direction. As the colour turns from white through yellow to red, we expect that acceptable threshold levels will be crossed (when going from yellow to red). Although adaptation is possible in many areas, the cost of adapting increases as major thresholds are crossed.

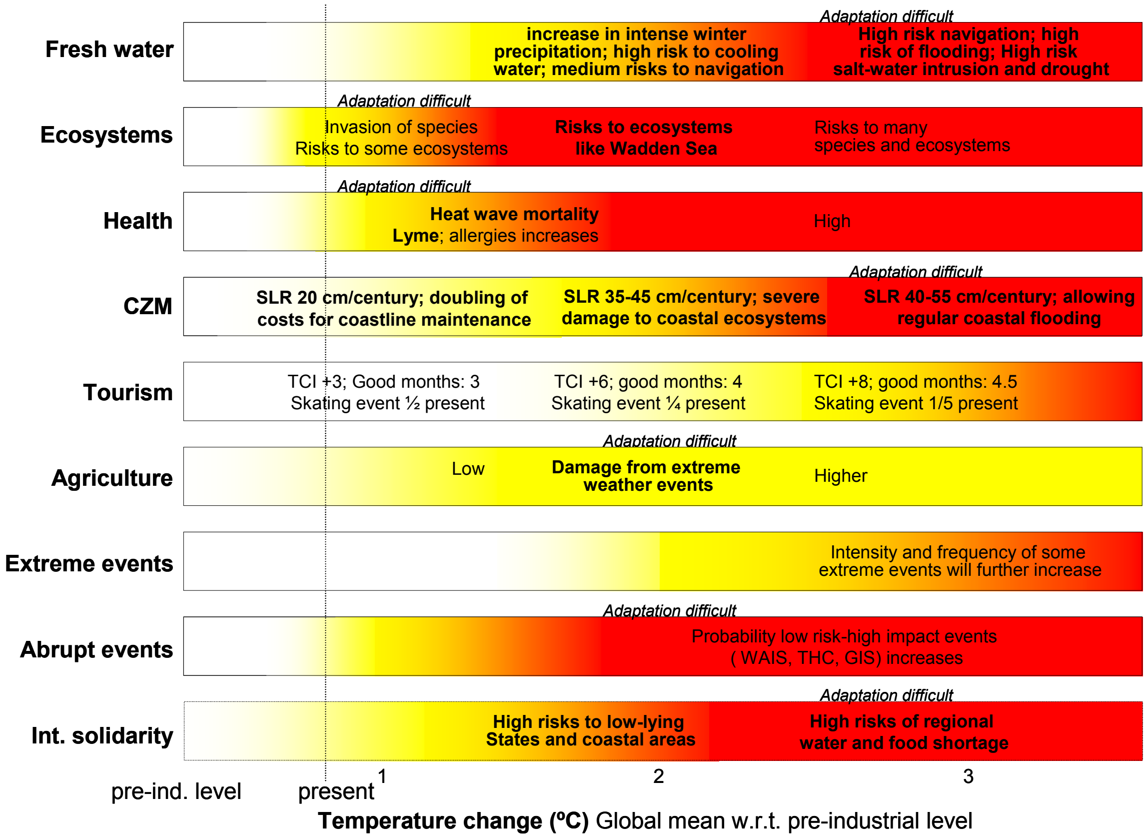

Figure 10.1. ‘Burning Embers’ figure for impacts relevant to the Netherlands (updated).

Clarification reasoning behind the ‘Burning Embers’:

- *Fresh water*: With increased temperatures the fresh water problems increase. The quantitative water sector aims at an adaptation based on a temperature increase of 1-2°C (compared to the 1990 situation), therefore compared with pre-industrial red starts between 2 and 3°C. Problems associated with drought and low flow can however already be problematic in an earlier stage.
- *Ecosystems*: Many changes are already observed in ecosystems. Many are adequate responses to cope with the changing climate but some are detrimental. The adverse impacts include the decline in population of migratory bird species and shifts in food webs in the North Sea. Negative impacts start to dominate beyond a 1°C temperature increase and increase in extent and magnitude beyond a 2°C temperature increase.
- *Health*: Health effects are expected with every temperature rise. Based on the lower threshold (i.e no increase in the chance of dying), climate change is only acceptable if adaptation will prevent all climate change induced heatwave deaths. Under a variety of assumptions (incl. adaptation), the upper acceptability threshold (i.e. acceptable annual risk of dying= 10^{-6}) will be exceeded with a temperature rise of +3°C (compared to 1960-1990). Climate change is expected to increase tick densities (due to increased winter survival and

prolongation of the tick season) and, subsequently, the risk on Lyme disease. The vast increases in tick-bites and Lyme disease in the past decade indicate that adaptation/prevention might be difficult. Even with a small an increase of 1% in the incidence of Lyme disease, the lifetime risk on morbidity due to climate change might become unacceptable. Climate-induced changes in pollen exposure may affect a large number of people, but there is insufficient quantitative information to predict the size of this effect.

- *Coastal zone management*: Major problems in the coastal zone for the coming 100 years are not foreseen. With higher temperatures, adaptation measures will become more drastic and urgent. However, this does not mean that we cannot cope with it. Sea level rise will have its impacts, but not to such an extent that we are surprised by it and that we cannot manage. Therefore, the colour sloping from white to red radiates and supports the message that developments and adaptations are gradually more drastic with rising temperatures.
- *Tourism*: In general, climate change has positive effects on tourism: outdoor conditions improve, and the 'holiday season' lengthens. Hence, no real dangers associated with 1 and 2 degrees increases in temperature. As a result of climate change, there will be fewer opportunities for ice skating on natural ice. As climate change intensifies, the likelihood of an *Elfstedentocht* ice skating event may decrease to around 20% of its current value, which is already low. This can be considered a loss of a traditional event in tourism & recreation, hence the orange score in the figure.
- *Agriculture*: Changes in Agriculture are largely driven by changes in markets and technology. Current systems will have to adapt to changes in climatic conditions. A gradual change, 4 degrees in 100 years, will not cause major problems for agriculture in the Netherlands. Key concerns are temporary water shortages and water excess that can result in yield reduction or even yield loss. Changes in climate extremes are a potential risk but so far climate scenarios present no clear picture on change in frequency and magnitude of extreme events such as late frost, hail, storms, etc. In conclusion agriculture will be able to adapt to gradual climate change but caution is needed in relation to extremes. Information on changes in extremes and the coping range of the sector is lacking to allow for quantitative conclusions.
- *Extreme events*: Starts with white since there were no or acceptable risk under pre-industrial conditions; between 1 and 2°C the intensity of some events (e.g. rainfall, length of heat waves may increase; it is not clear whether the frequency will increase) increases requiring adaptation, but adaptation is considered possible; red at the right end (about 2°C compared to current situation): adaptation is still possible but more costly. Thresholds may be passed if no adaptation takes place, but this is not clear.
- *Abrupt events*: Starts with white since there were no or acceptable risk under pre-industrial conditions; red at the right end (and gradual change in between): although the risk is very low (not likely in this century), the effects can be that enormous (financially, socio-economically, directly in the Netherlands or indirectly affecting the Netherlands) that we are not willing to accept any risk that these events will happen.
- *International solidarity*: Although no specific research has been conducted with regard to international solidarity, stakeholders in the previous project indicated the importance of this aspect; research has indicated that risks of food and water shortage, as well as general economic impacts will be greater for developing countries, even for temperature increases below 2°C.

Risks rapidly become unacceptable for some of the sectors at relatively low increases in temperature, sometimes even close to 1°C. A warming of around 0.8°C since pre-industrial levels has already occurred. There are obvious costs for both autonomous and proactive adaptation; but these costs as well as the costs of taking mitigation action have not been covered in this report. This is because comprehensive information was not available at the sectoral level for all the impacts studied.

The previous report of the project team argued on the basis of the stakeholder discussions that the driving factors for engaging in discussions on dangerous climate change in the Netherlands are the losses to unique ecosystems such as the Wadden Sea and the coastal belt; the high economic, but also socio-political costs of coastal adaptation; the implications of the changing precipitation regime for navigation, agriculture, and infrastructure; impacts on tourism and health; irreversible and abrupt events with high associated risks; and last but not least important - the impacts on vulnerable societies and countries especially in the developing world.

During the workshop with Dutch experts organised in May 2006 (see Annex), the participants stated that a figure such as the burning embers figure contains much information but remains difficult to comprehend for the general public. It was necessary to make the figure more sensible and relevant for lay people. This led to a first draft of a follow-up figure (see Figure 10.2). While the basis of this figure does not contain colours, a value judgment can be added by posing questions. The figure could be an online tool for the public to assess what they consider unacceptable. This could be done by framing questions in a way that people will have to value the occurrence of climate impacts ("Do I mind if climate impact X happens?") By answering these questions, it is possible to add colour to the figure, and to show people what they themselves consider 'dangerous' climate change. For impacts where there is still a lot of uncertainty, such as the large-scale abrupt events, questions could be posed in a way that explicates the uncertainty ("Do I mind that there is a probability X that climate impact Y happens?"). It is noted that such a figure or tool does not in itself address the relative importance people attach to different sectors (for example, the impacts on the coastal zone could be considered much more important than impacts on the tourism sector). The following figure contains questions composed by the research team. This is a first attempt to provide questions relevant for the project. However, many more questions can be thought of and could be included in such a figure.

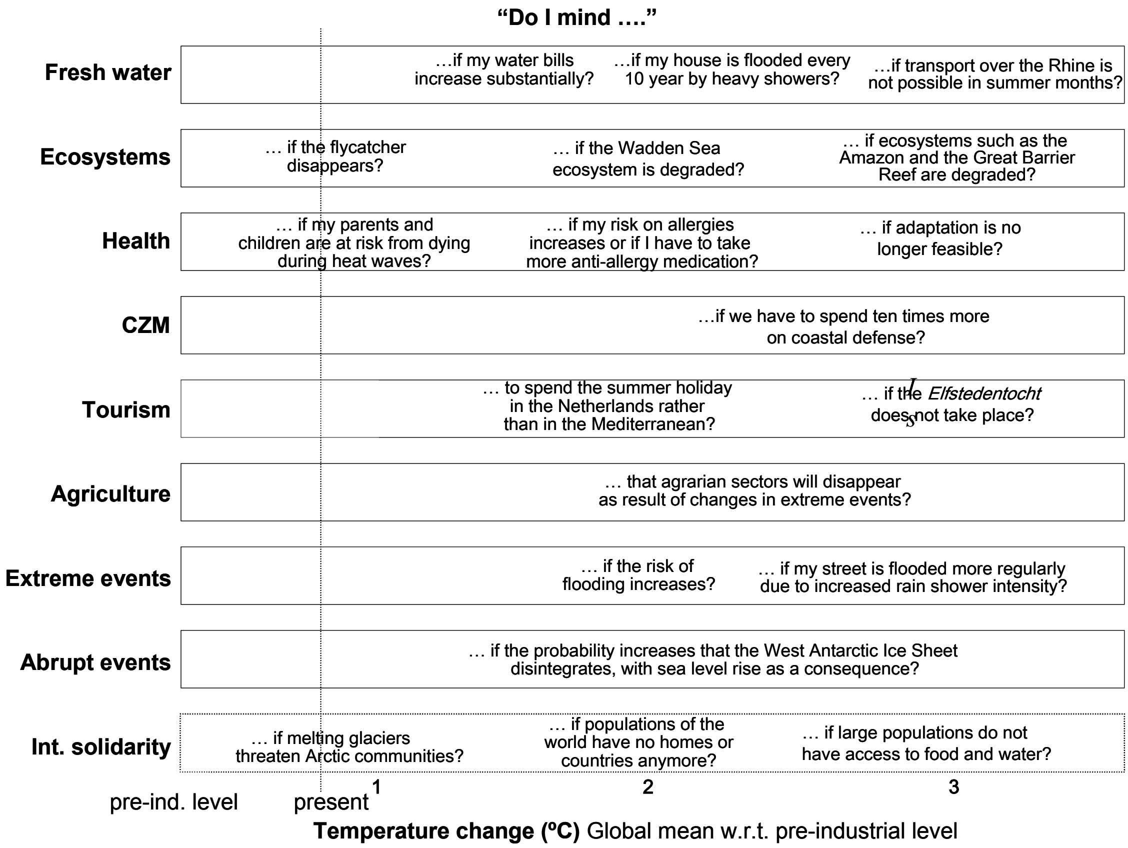

Figure 10.2. 'Burning Embers' figure highlighting issues of relevance for Dutch residents.

10.8 Temperature or concentration targets

Although in 1996 and 2001, the Netherlands and the EU chose to express their targets in terms of temperature increases and GHG concentrations, the realisation that the climate sensitivity might be higher than previously assumed, make many argue in favour of temperature targets as opposed to targets related to concentration levels, since the latter is a less certain parameter than global mean temperature for determining impacts. Furthermore, a long-term stabilisation of concentrations target does not take into account the inertias in the system. This means that the temperature consequences are not felt for decades to come and that a considerable warming is already committed. This means that if we wish to stabilise global temperature at 2ºC above pre-industrial levels, we need to ensure that concentrations of CO_2 equivalence are not much higher than 400 ppmv. This still does not mean that we have a 100% probability that if we stabilise at 400 ppmv that we can limit temperature rise to 2ºC above pre-industrial levels. This is because of the large number of uncertainties in the system.

10.9 Policy recommendations

This report has highlighted the observed and expected impacts of climate change on several areas of importance to the Netherlands, and has explained how these impacts can be seen as potentially dangerous in the sense of Article 2 of the Climate Change Convention. In this regard, the findings of this report are also relevant for the Adaptation Programme for Spatial Planning and Climate (*Nationaal Programma Adaptatie Ruimte en Klimaat*; ARK), which aims specifically to address the nature and magnitude of observed an expected climate impacts.

This report concludes that the impacts of climate change on the Netherlands can be classified into three categories in relation to a possible 2°C rise in global mean temperature from pre-industrial levels:

- Mainly positive effects expected: tourism and recreation and the agricultural sector may stand to gain if food production falls in other parts of the world;
- Mainly negative effects expected: for health, fresh water, and coastal zone management. For these sectors, we may have to invest heavily in adaptation in order to maintain the status quo. For species and ecosystems it is clear that there will be adverse impacts, which means that a combination of mitigation and adaptation is needed;
- Unclear: for large-scale abrupt events, there remains much uncertainty. Most scientists believe that the risk of abrupt events will increase with increasing global mean temperatures.

It can be seen that some of the impacts have an explicit international component, which can be regarded as relevant for the determination of what is dangerous for the Netherlands. These include the potential impacts of abrupt events, which would have global impacts by definition; ecosystems, which are at larger risk in other parts in the world than in the Netherlands; and the impacts on other, more vulnerable regions and countries. However, there are also some impacts that have an international component, which could imply a positive outcome for the Netherlands, such as increased tourism in the Netherlands, or shifts in agricultural production.

In general, the risks for climate change impacts increase gradually (although not always linearly) with increasing temperatures. While for the tourism sector a temperature increase of 3ºC compared to pre-industrial levels may seem acceptable; and impacts on agriculture may be limited, for the bulk of the other sectors a 1-2ºC rise in temperature implies approaching threshold limits. We believe that beyond a 2ºC global warming in relation to pre-industrial levels the probability of occurrence of low-probability high-risk events increases. Agreeing to the 2ºC target implies that ecosystems and species would be at considerable risk, and that numerous proactive adaptation activities would have to take place in the fresh water, health, coastal zone management and agricultural sectors. Furthermore, the impacts that would still occur on other vulnerable regions of the world should not be neglected. The 2°C target could imply adverse impacts on other, more vulnerable countries.

As we have already warmed around 0.8°C since pre-industrial times, this means that a stronger focus on adaptation some of the abovementioned sectors is justified. However, this is not to suggest a total shift towards adaptation policy. On the contrary, the current and expected impacts on, for example, ecosystems around the world, as well as vulnerable countries emphasise the importance of mitigation policies.

According to recent literature, to stay with considerable certainty below a 2ºC warming limit implies stabilising CO_2 equivalent concentrations at 400 ppmv. This is considerably lower than the previous concentration target of 500-550 ppmv. Further relaxing the temperature target raises the risk of putting larger number of species and ecosystems at risks of extinction and would neglect the impacts of climate change in other parts of the world. Clearly, while such a target is a political goal, committing to such a target only makes sense when other developed countries also soon engage in such commitments, followed later by all the other countries.

According to VROM (2006), the short-term climate targets for the Netherlands for 2010 will be achieved. Furthermore, it also states that it is technically feasible to avoid exceeding the 2°C target. This conclusion seems premature, given that achieving the Kyoto targets certainly does not ensure in itself that the long-term ambition of the Netherlands will be fulfilled. Furthermore, as indicated in this report, there is still much uncertainty on the stabilisation pathway that is needed to stay below 2°C. Given that we are already well on our way towards this temperature increase, and given that it is more probable that lower stabilisation levels are required than initially thought, we recommend to examine which emission and stabilisation pathways need to be followed to achieve the Netherlands' long-term political ambitions.

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Annex 1 Workshop Report

Joyeeta Gupta & Harro van Asselt, Institute for Environmental Studies, Vrije Universiteit Amsterdam (IVM-VU)

Introduction

On 31 May 2006, a workshop was organised by the project focusing on Assessing Climate Change Impacts for the Netherlands (HOT-4). The workshop was held at the Netherlands Ministry of Housing, Spatial Planning and Environment and was chaired by Prof. Rik Leemans (Wageningen University) 27 experts attended the meeting.

Summary of presentations

The meeting began with a presentation by Joyeeta Gupta (Institute for Environmental Studies, Vrije Universiteit Amsterdam) of the project purpose and the purpose of the workshop. It focused on the three schools of thought regarding how dangerous climate change can be scientifically interpreted. It looked at the disciplinary approaches to defining climate change and presented a draft summary figure of the impacts of climate change on the Dutch population to the audience to keep in mind for the discussions.

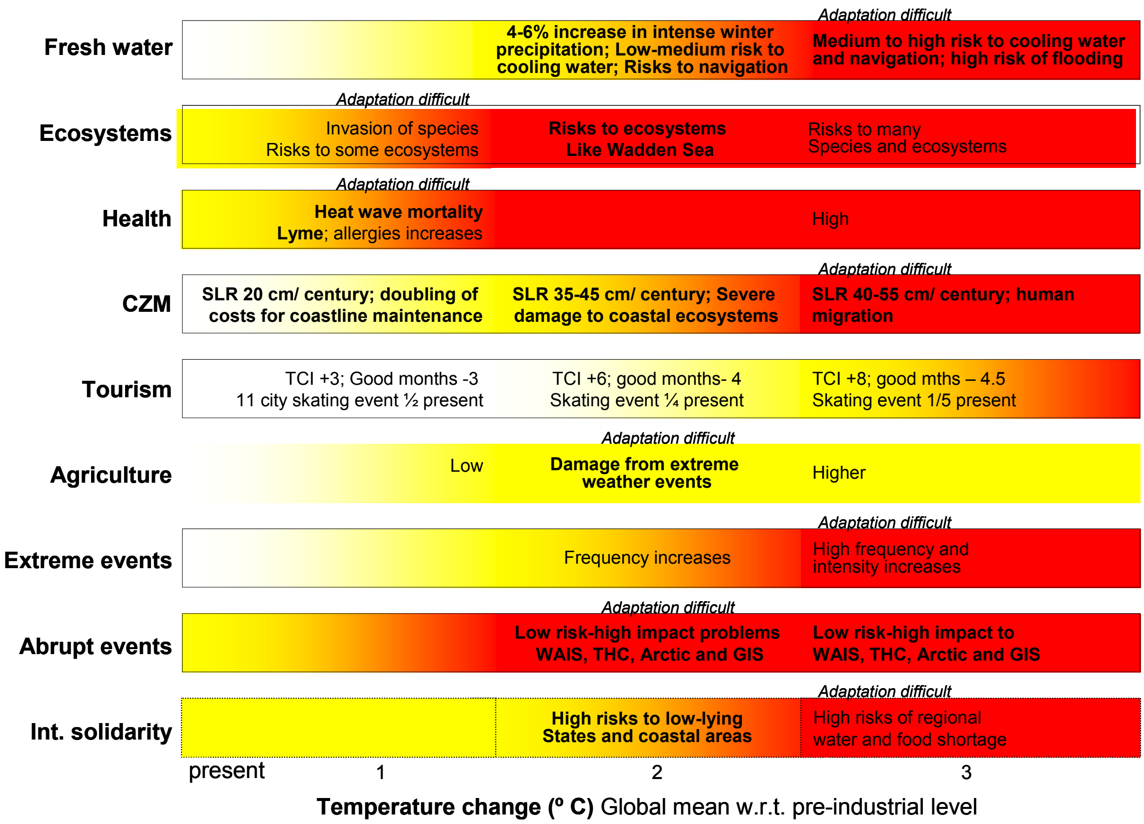

Figure 1.1. Burning Embers Figure for the Impacts on the Netherlands

The discussion focused mostly on clarificatory questions and suggested that we should determine who our target audience is, and make the figure more accessible to a wider group of social actors in by translating it into real world concerns for people.

This was followed by a presentation by Bill Hare (Potsdam Institute for Climate Impact Research) who focused on recent approaches to define dangerous climate change, some recent work on impacts and on his perception of what is dangerous climate change. He argued that the operationalisation of Article 2 UNFCCC requires answering 4 basic questions: (1) what are your limits?; (2) what are your responsibilities to others and their limits?; (3) what are your choices and options?; and what are you going to do about it? His presentation emphasised that (a) some impacts are even more serious than expected; and (b) that deciding what is dangerous climate change requires not just seeing what the impacts will be on the Netherlands but also seeing how this may impact on the much more vulnerable countries of the world. In particular, he showed that for water shortage, there might be a threshold between 1.5 and 2.5°C above pre-industrial levels. Food security in different regions of the world and in particular developing countries could be endangered at a temperature increase of 2-2.5°C above pre-industrial levels. In general, developing countries would suffer economic losses at 2°C.

Rik Leemans then presented the impacts of climate change on ecosystems in the world, Europe and the Netherlands. He explained that some indicators were selected for four elements of ecosystems that may be affected at a global, regional and local level. The four elements include plants and vegetation, mammals, birds, and marine species. Indicators for each of these elements were studied, and these revealed that beyond a 1-°C warming, phenology (e.g. the timing of leaves and flowers) is out of sync for all parts of the world; that beyond a 1 degree rise in mean temperatures, the physiology changes and sinks may become sources, certainly at global level; and that major risks to biodiversity set in beyond a zero degree rise in temperature. Although there are no studies on mammals in the Netherlands, between 1-2°C mammals become increasingly vulnerable. Birds in the Netherlands may be more sensitive to a small rise in temperature (even less than 1°C) than globally. Given the fewer marine species in the Netherlands, coral reefs and marine life is more likely to be affected at European and the global level. The analysis concludes that the most recent scientific literature shows that climate change impacts may occur earlier than projected by the Third Assessment Report of IPCC (TAR). The impacts include changes of the terrestrial carbon balance, which after continuing its role as sink for few decades could change into a source, rapid phenological responses of plants and animals, and changes in distribution, structure and composition of most ecosystems (not only in the boreal zone as previously stressed). There is now growing evidence for a high vulnerability of a larger fraction of species (globally ~25% by 2100, for some biota as low as 1% or as high as 43%) becoming committed to extinction than previously assessed. Changes in disturbance and other stresses such as wildfire, invasive species and pollution are likely to exacerbate climate change impacts.

Responses of endemic species (i.e. unique species confined a small area) geographic range size are overwhelmingly negative with resulting impacts on biodiversity and biodiversity hotspots, and strongly sensitive ecosystems are coral reefs, Arctic systems, mountains, Mediterranean systems and savannas. In most cases, species persistence requires migration rates that exceed their natural adaptive capacity. These effects, combined with landscape fragmentation through land use change, limit natural adaptation especially for plant species, and increase their risk of extinction during this century. Marine ecosystems and species appear more able to shift range rapidly than many terrestrial species. All these impacts may lead to mainly detrimental changes in ecosystem services. Impacts on sustainable development and livelihoods of people depending on the ecosystems remain, however, difficult to estimate.

The TAR already established in 2001 that beyond 2ºC global mean temperature increase compared to pre-industrial levels, the risks for negative impacts on species and ecosystems rapidly increased. This analysis shows that this assessment was too positive. Risks for impacts on many local and regional species and ecosystems already rapidly increase just beyond 1ºC global mean warming and are also not negligible at lower temperature increases.

To limit the risks for impact of climate change on ecosystems two approaches have to be taken. First, climate change has to be limited by limiting and reducing greenhouse gas emissions. This seems economically and technologically feasible. Second, the resilience of species and ecosystems has to be increased. One of the most effective strategies to achieve this is to reduce other stresses on species and ecosystems and enhance conservation efforts. However, the cascade of uncertainties from climate change projections through species to ecosystem responses remains a significant barrier to develop coherent and detailed regional policy planning responses.

Hendrik Buiteveld (RIZA) then made a presentation of the impacts on the Netherlands in terms of the fresh water system. He explained that five indicators in the area of water were selected for study. These include river discharge, water inconvenience, access to clean water, navigation, and cooling water. The research indicated that in general river discharge is expected to increase in the winter and decrease in the summer. There is a likelihood of greater water inconvenience – flooding at higher temperatures. Although the Netherlands already experiences a minor water deficit in the summer months, this is unlikely to be a major problem, given the reservoirs already being built. Navigation may be negatively affected in summer months if discharges drop below 1250 cubic metres per second. Surface water temperatures should not be higher than 23ºC in the summer and 16ºC in the winter for cooling water discharge. Since water temperatures are influenced both by cooling water discharges upstream and by climate change, this has to be carefully monitored. While adaptation to the changing access to clean water is possible through the construction of water reservoirs, it becomes more difficult, although not impossible, to arrange for spatial solutions to the river discharge problem to manage rural flooding, cooling water, and navigation problems. The science underlying this information is partially based on existing laws/policies, partly on well-established scientific information while some of the extrapolation is partly based on reasoning.

Maud Huynen (ICIS, Maastricht University) then explained the health impacts of climate change. In the health sector, three indicators were chosen. These include increased mortality as a result of heat waves, increased risk of Lyme disease, and an increased risk of pollen allergies. Past heat waves in the Netherlands have resulted in an excess mortality of 38.9 excess deaths (12.8%) per heat wave day. However, part of the excess mortality during heat waves must be viewed as “only a slight forward displacement of deaths”. The other part of the excess mortality, however, relates to avoidable deaths and substantial loss of life. The most vulnerable to heat waves are senior citizens, persons with cardiovascular or respiratory disease, and young children. The view that climate change will have an impact on heat wave mortality is well established. Climate-change-induced heat wave mortality might become unacceptable under various assumptions regarding adaptation capacity and “forward displacement”.

The expectation that climate change has an impact on Lyme is well established, although more quantitative research is required. Tick densities are positively correlated with human Lyme disease. With less harsh winters, it is expected that tick survival, and, consequently, tick densities will increase. In addition, a significant prolongation of the tick-season is expected. If climate change would result in a (possible) 1% increase in disease incidence, the acceptable lifetime risk on morbidity - induced by climate change- might be exceeded.

Weather conditions affect the timing/duration of the pollen season, the quantity of pollen produced and the geographic distribution of flowering plants. However, the impact of climate change on allergic disorders is uncertain and there is a need to better understand this relationship between the changing climate and allergic disorders.

A wide range of adaptation options are possible which include legislative, technical, educational and behavioural changes that could enhance the ability of humans to overcome these risks. What is clear is that risks increase as temperature rises, but that adaptation may reduce these risks somewhat. More research on adaptation capacity is required.

She also explained the work of Bas Amelung on impacts on tourism. Climate change will generally have a positive influence on tourism and recreation in the Netherlands. Overall conditions for outdoor tourism activities (represented by the annual mean Tourism Climatic Index) will improve, and in summer, the period with very good circumstances will lengthen substantially, perhaps even by several months. One of the drawbacks of climate change for tourism and recreation in the Netherlands is the decreasing availability of natural ice in winter that is of sufficient quality for ice-skating. This trend is symbolised by the projected decreasing likelihood of *Elfstedentocht* ice-skating events.

Jan Verhagen (Plant Research International) presented the impacts on agriculture . Three indicators were selected to represent the potential impacts on agriculture. These include a change in crop productivity, damage from extreme weather events and changes in commodity prices. Since agricultural activity has an extremely long history and farmers are used to dealing with weather instabilities, it is argued that agricultural systems will not be severely impacted by climate change, as farmers will adapt. However, crops will be vulnerable to extreme weather conditions (and salt water intrusion) and although one can insure against some of these risks, there will still be impacts on commodity prices. As the Netherlands is increasingly engaging in commodity trade, impacts of climate change in other countries may raise the price of commodities affecting the market situation. This may mean that the Netherlands can profit by becoming more competitive against other countries where the impact may be quite severe. Much of this is based on extrapolating and reasoning from existing literature.

Finally, Mick van der Wegen (UNESCO-IHE) discussed sea level rise. Having a long history of battling sea level rise, the Netherlands is well prepared to deal with the next three indicators related to coastal zones. The first indicator is coastal squeeze, where a rising sea level leads to a shrinking of the coastal zones: Dune type of environments will slowly be changed into hard protection measures like dike systems. The second indicator is the risk of flooding. In order to maintain the current risk standards, major protection measures are needed against rising costs in case of higher sea levels. The same holds for the frequency and magnitude of exponentially rising costs in case of higher sea levels. Additionally a rising sea level brings with it a higher uncertainty. The reason for this is that the behaviour of the North Sea system induced by higher sea levels is not known from history. The same holds for the frequency and magnitude of extreme events like storms. Salt-water intrusion is the third indicator. Higher sea levels will cause salt surface water and groundwater to intrude further inland, impacting the freshwater supply and ecosystems. While in the short-term salt water intrusion can be prevented through membrane filtering techniques, in the longer-term, this may be difficult to deal with.

Discussion and conclusions

In the discussion that followed, there were some clarificatory questions but mostly a focus on the usefulness of the approach selected to communicate the information to the public. Was the figure alarmist?; did it communicate well?; were extraterritorial impacts included sufficiently?; did it allow the reader enough space to make his or her own conclusions?; should the colour coding be removed? There were some suggestions made to actually give the revised figure more publicity to create greater engagement from the public. A new figure was discussed informally in the group and is presented below.

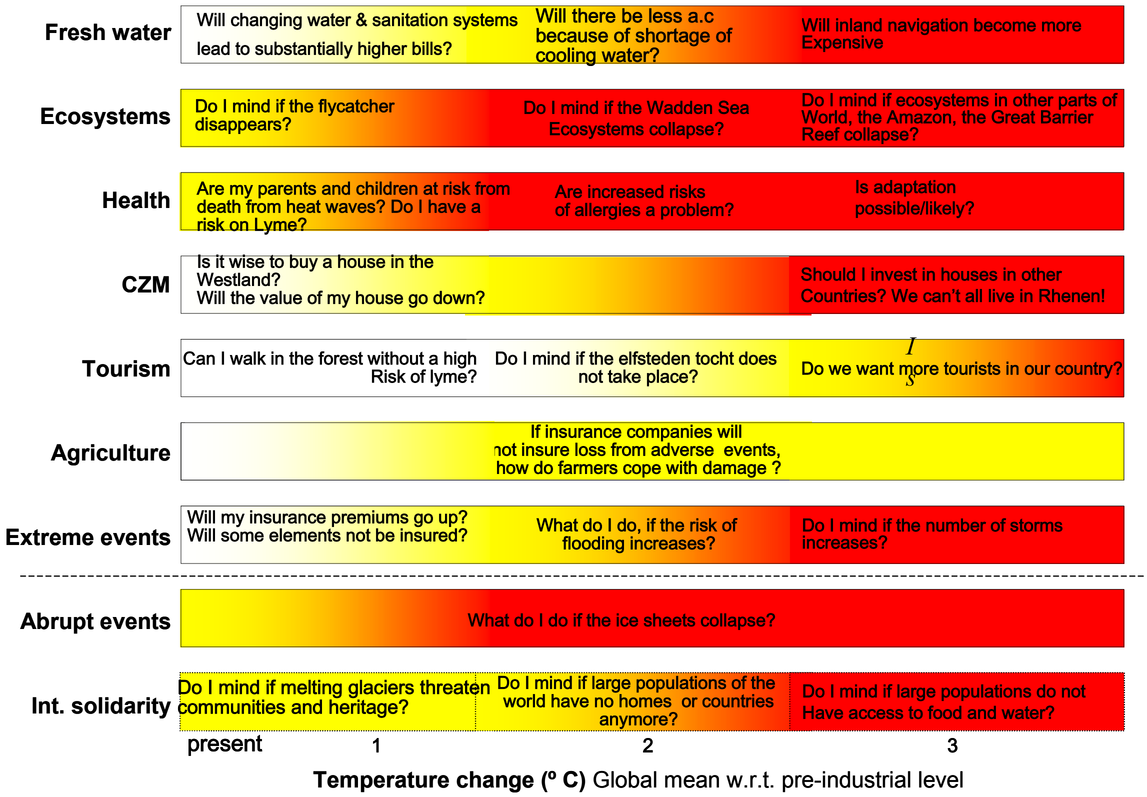

Figure 1.2. 'Burning Embers' figure highlighting issues of relevance for Dutch residents.

Participant list

Harro van Asselt	IVM, Vrije Universiteit
Joris den Blanken	Greenpeace
Joop van Bodegraven	Ministerie van LNV
Marc-Jeroen Bogaardt	LEI, Wageningen Universiteit
Bert Borst	Ministerie van VROM
Wouter Botzen	IVM, Vrije Universiteit
Richard Braakenburg van Backum	Ministerie van V&W
Elma Brasser	IVM, Vrije Universiteit
Hendrik Buiteveld	RIZA
Bas Clabbers	Ministerie van LNV
Joost Dekkers	RIZA
Luit-Jan Dijkhuis	Ministerie van V&W
Ronald Flipphi	Ministerie van VROM
Ron Franken	Milieu- en Natuur Planbureau
Joyeeta Gupta	IVM, Vrije Universiteit
Bill Hare	Potsdam Institute for Climate Impact Research
Maud Huynen	ICIS, Universiteit Maastricht
Rik Leemans	Wageningen Universiteit
David van Lennep	ABN Amro Insurance and Weather Derivatives
Willem Ligtvoet	Milieu- en Natuur Planbureau
Gerard van Noort	Aeolis Forecasting Services BV
Donald Pols	Milieudefensie
Hans Schneider	CEA
Sible Schöne	Klimaatbureau
Jan Verhagen	PRI, Wageningen Universiteit
Henk Wardenaar	Ministerie van V&W
Mick van der Wegen	UNESCO-IHE

Workshop agenda (in Dutch)

Agenda Workshop HOT-4: Gevaarlijke effecten van klimaatverandering in Nederland

09.00-09.30 *Ontvangst en koffie*

Deel 1: De context – Gevaarlijke effecten van klimaatverandering voor Nederland en besluitvorming (in Engels)

Welkom en uitleg - Joyeeta Gupta (IVM)

09.45-10.15 Artikel 2 van het Klimaatverdrag – Bill Hare (PIK)

Deel 2: Gevaarlijke effecten van klimaatverandering voor Nederland voor bepaalde categorieën (15 minuten presentatie/10 minuten discussie)

10.15-10.40	Ecosystemen en natuurontwikkeling – Rik Leemans (Wageningen Universiteit)
10.40-11.10	*Koffie*
11.10-11.35	Water – Hendrik Buiteveld (RIZA)
11.35-12.00	Gezondheid – Maud Huynen (ICIS, Universiteit Maastricht)
12.00-13.00	*Lunch*
13.00-13.25	Landbouw en internationale handel in landbouwproducten – Jan Verhagen (Wageningen Universiteit)/Marc-Jeroen Bogaardt (LEI)
13.25-13.50	Toerisme – Bas Amelung (ICIS, Universiteit Maastricht)
13.50-14.15	Zee en kustgebied – Mick van der Wegen (UNESCO-IHE)
14.15-14.25	*Koffie*

Deel 3: Discussie gevaarlijke klimaateffecten voor Nederland

14.25-14.40	Presentatie eindfiguur
14.40-16.00	Gestructureerde discussie met volgende vragen: - Wat is de communicatiewaarde van het eindfiguur? Hoe kan het figuur het beste onder de aandacht worden gebracht? - Wat zijn de informatiebehoeften van beleidsmakers? Is er voldoende informatie beschikbaar voor beleidsmakers om beslissingen te nemen? - Zijn er nog lacunes over hoe de effecten vertaald kunnen worden naar mitigatiemaatregelen (en de bijkomende gevolgen voor de economie) en hoe gaan we om met deze lacunes?
16.00-16.15	Sluiting – Rik Leemans (WUR)