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Terrestrial
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Analysis and
Modelling

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Section 5 and 6

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Detailed report, related to overall project duration
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Section 5 – Executive publishable summary, related to the overall project duration

Contract n°	EVK2-2000-00075	**Project duration:**	01.01.2001-30.06.2004
Title	Advanced Terrestrial Ecosystem Analysis and Modelling		

Objectives

ATEAM's primary objective was to assess the vulnerability of human sectors relying on ecosystem services[3] with respect to global change. We consider vulnerability to be a function of potential impacts and adaptive capacity to global change. Multiple, internally consistent scenarios of potential impacts and vulnerabilities of the sectors agriculture, forestry, carbon storage, water, nature conservation and mountain tourism in the 21st century were mapped for Europe at a regional scale for four time slices (1990, 2020, 2050, 2080).

Scientific achievements

In ATEAM, vulnerability was assessed as the degree to which an ecosystem service is sensitive to global change, plus the degree to which the sector that relies on this service is unable to adapt to the changes. We used a set of multiple, internally consistent socio-economic, climate, land use and nitrogen deposition scenarios, and developed a comprehensive modelling framework for projecting the dynamics of ecosystem services provided by European terrestrial ecosystems at a regional scale[4]. The ability of human sectors to implement planned adaptation measures was considered using indicators of adaptive capacity. A dialogue with stakeholders was part of the assessment from the start of the project in order to provide applicable results to the management of natural resources in Europe.

We found that the provision of essential ecosystem services will change significantly with global change during the 21st century. Specific vulnerabilities of sectors and/or regions can be reduced by specific adaptation strategies:

- Land use change projections based on socio-economic and climatic changes show an overall decline in arable land in Europe. Climatic changes will shift crop suitability in agricultural regions. While the suitable area for some crops expands, some current agricultural areas become too hot and too dry to support agriculture for any crop type. To make use of the climate protection potential of biomass energy, shifts in suitable areas should be taken into account.
- In the forestry sector climate and land use changes are anticipated to have an overall positive effect on growing stocks in Northern Europe. However, negative effects were projected in other regions, e.g. drought and fire pose an increasing risk to Mediterranean forests. Management is paramount in the development of growing stock and forest productivity -- intensive, sustainable forest management keeps the net annual increment at a high level.
- After an initial increase, the total terrestrial carbon sink strength (plants and soil) is projected to decline over time in Europe. In particular, the decrease in soil organic carbon is significant for all scenarios, calling for increased attention to management practises that sustain soil fertility.
- In the water sector, climate change tends to increase the numbers of basins in southern Europe with water scarcity[5] and may produce simultaneously more severe droughts and more extreme floods in some areas of north-western Europe. Changes in the timing of river flows, largely due to the reduction in the amount of snowfall, will affect both navigation and run-of-river hydropower potential. Hydropower plants might adapt their water storage strategies to prevent exceeded storage capacity at peak times.

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[3] Ecosystem services are the conditions and processes through which ecosystems, and the organisms that make them up, sustain and fulfil human life

[4] The framework covers all EU countries, plus Norway and Switzerland at a resolution of 10'x10' (ca. 15x15 km).

[5] Water availability per capita falls below 1000 m^3 $capita^{-1}$ $year^{-1}$.

- In the nature conservation sector accelerated extinctions rates indicate rapid biological impoverishment for most regions. This adverse trend for biodiversity could be mitigated by flexible management of nature reserve areas to maintain the conservation effect under changing environmental conditions.
- The mountain tourism sector will be impacted negatively in both winter and summer. In winter the elevation of reliable snow cover is expected to rise between 200 and 400 m, leaving many ski areas without sufficient snow. In summer the number of extreme heat days is likely to increase, thereby impacting on the attractiveness of mountain activities and increasing the number of mountaineering accidents.
- In comparison between European regions, the Mediterranean seems most vulnerable within Europe. Multiple potential impacts on multiple sectors were projected. These include water shortages especially in the summer months when demand peaks due to tourism, increased fire risk in the forestry sector, losses in the carbon storage potential, northward shifts in the distribution of tree species like maritime pine and cork oak, and losses of agricultural potential due to drought. In the Mediterranean these potential impacts combine with low adaptive capacity.

Main deliverables

ATEAM has produced two main products: (1) A CD-ROM with the interactive ATEAM mapping tool displaying the full range of charts and maps of results with exhaustive documentation and summarised conclusions. (2) A journal special issue with five summarising scientific papers to be published probably by peer-reviewed Springer journal *Regional Environmental Change*. In addition to this special issue, numerous papers have been and will still be published as a result from the ATEAM project.

Socio-economic relevance and policy implications

This work contributes to the understanding of Europe's vulnerability to global change. Specifically, ATEAM assesses the rate and extent of climate and land use change, potential changes in ecosystem service supply and the vulnerability of key human sectors. Existing understanding of the dynamics of European ecosystems (managed and unmanaged) in the form of data and models, were assembled in a coherent framework. The ATEAM results facilitate sustainable environmental management and help evaluate the effectiveness of implementation measures such as the European Biodiversity Strategy. Project findings on Europe's carbon storage potential provide input to the debate around the Kyoto Protocol and support the design of climate protection strategies. The project actively promoted the dialogue between stakeholders and scientists to increase mutual understanding and the usefulness of scientific results. All project conclusions have been shaped by this dialogue process.

Conclusions

The full range of environmental impact scenarios provides spatially explicit projections of ecosystem services over time, including for the first time the variation over multiple plausible scenarios. This variation may be high, however, a considerable amount of it is due to the socio-economic pathway we *choose* to take. The set of multiple plausible global change scenarios showed severe changes in European climate and land use in the next century. Though some of the expected impacts may be considered positive (e.g. increases in forest area and productivity), and others hold potential opportunities for the future (e.g. "surplus land" for extensification of agriculture), most of the anticipated changes have negative impacts on ecosystem service supply, and therefore human society (e.g. declining soil fertility, increased fire risk, biodiversity losses). The main trends in anticipated environmental impacts of global change seem clear enough to trigger both immediate action and further inquiry.

Dissemination of results

Dissemination of our results and conclusions takes place via digital atlas of results on CD-ROM, peer-reviewed papers, including journal special issue and contributions to large book projects, an archive of input data and results hosted by a permanent institution, workshops, conferences, public and news media, teaching activities, and via our project website.

Keywords

vulnerability, stakeholder dialogue, adaptive capacity, potential impacts, carbon storage, Kyoto Protocol, biodiversity, environmental management, agricultural management, biomass energy, tourism, water, forestry management

Section 6: Detailed report, related to overall project duration

Please note: All Figures but Figure 1 are appended in Annex 3.

6.1 Background (description of the problem to be solved)

Over the next century society will increasingly be confronted with global changes such as population growth, pollution, climate and land use change. By 2050, the human population will probably be larger by 2 to 4 billion people. An increasing number of people, with increasing consumption of food and energy per capita have boosted the emission of nitrogen to the atmosphere, resulting in eutrophication of the environment via deposition. Furthermore, within the next decades the atmospheric carbon dioxide concentration will at least double compared to pre-industrial times, while the global average surface temperature is projected to increase by 1.4-5.8°C. Land use changes will have an immediate and strong effect on agriculture, forestry, rural communities, biodiversity and amenities such as traditional landscapes, especially in a continent as densely populated as Europe. Discoveries like these have led to a growing awareness of our vulnerability to global change. In addition to immediate global change effects on humans (e.g. hazards like floods or heat waves), an essential part of our vulnerability is due to impacts on ecosystems and the services they provide. Information about possible environmental impacts that matter to society can support planned adaptation. In a pan-European assessment of global change vulnerability we therefore looked at ecosystems in terms of the services they provide to human sectors, such as carbon storage, food production, biodiversity, scenic beauty, and many more.

Projection of socio-economic and biophysical variables to the next century cover a range of possible futures, without assigning probabilities or likelihood to any individual scenario. To deal with this unknown uncertainty, we based our global change projections on a range of coarse narratives, the so-called marker scenarios, or IPCC[6] Special Report of Emission Scenarios (SRES) A1f, A2, B1 and B2. We used four different general circulation models (GCMs) to simulate possible climatic changes resulting from these four emission scenarios. We then developed a set of land use and nitrogen deposition scenarios that are linked to the climate scenarios and the socio-economics derived from the SRES. This resulted in a consistent set of scenarios at high spatial resolution for the main global change drivers in Europe (10’ x 10’ grid for EU plus Norway and Switzerland). We used a set of state-of-the-art ecosystem models to translate global change scenarios into potential environmental impacts. In a stakeholder-guided process we selected a range of indicators for ecosystem services that are related to the sectors agriculture, forestry, carbon storage and energy, water, biodiversity and tourism.

To at least partly capture the ability of regions to adapt to changes we developed a spatially explicit generic macro-scale index of adaptive capacity. Combining this index with our results on potential environmental impacts we produced spatially explicit maps of vulnerability and its components for multiple scenarios and time slices within the next century (10’ x 10’ grid resolution over EU15 plus Norway and Switzerland, baseline 1990, future time slices 2020, 2050, 2080, scenarios based on the Special Report of Emissions Scenarios A1fi, A2, B1, B2). The full range of environmental impact scenarios from our pan-European assessment provides spatially explicit projections of ecosystem services over time, while being honest about the attached uncertainties. The results add to the basis for discussion between different stakeholders and policy makers, thereby facilitating sustainable management of Europe’s natural resources under global change.

In the face of global change, these were the questions that drove our project:

- Which regions in Europe are most vulnerable to global change?
- Which scenario is the least harmful for a sector within Europe such as agriculture, forestry, etc.?
- Which sectors are the most vulnerable in a certain European region?

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[6] IPCC = The Intergovernmental Panel on Climate Change.

6.1 Scientific/technological and socio-economic objectives

The specific scientific objective of the ATEAM project were (1) to assess potential impacts of global change on ecosystem services[7] in Europe, and (2) to translate these impacts into maps of our vulnerability (spatially explicit at 10'x10', time slices 1990, 2020, 2050, 2080). Multiple global change drivers and scenarios were considered. Included in the assessment was a strong dialogue with stakeholders to provide research results that are applicable to the management of natural resources in Europe. The underlying general objective of the vulnerability assessment was to inform the decision-making of stakeholders about options for adapting to the effects of global change and thereby to facilitate environmental management and sustainable development.

6.2 Applied methodology, scientific achievements and main deliverables

Vulnerability is defined as the undesirable state of being open to damage. By assessing future vulnerability under different scenarios this unpleasant state can perhaps be avoided by adaptation measures. ATEAM defines vulnerability as *the degree to which an ecosystem service is sensitive to global environmental change and the degree to which the sector that relies on the service is unable to adapt to the changes* (WP1). This definition contains three elements which determine vulnerability of an area: (1) its exposure to environmental change, (2) the sensitivity of the ecosystem service to that change and (3) the adaptive capacity of the sector which relies on the ecosystem service. Exposure and sensitivity of a region result in *potential impacts* which sometimes can be avoided or modified by adaptation. Potential impacts (the resultant of exposure and sensitivity) and adaptive capacity constitute a region's vulnerability. In this section we will give a brief overview over each methodological elements. then we will describe each elements and the achieved results in more detail in subsequent sub-sections.

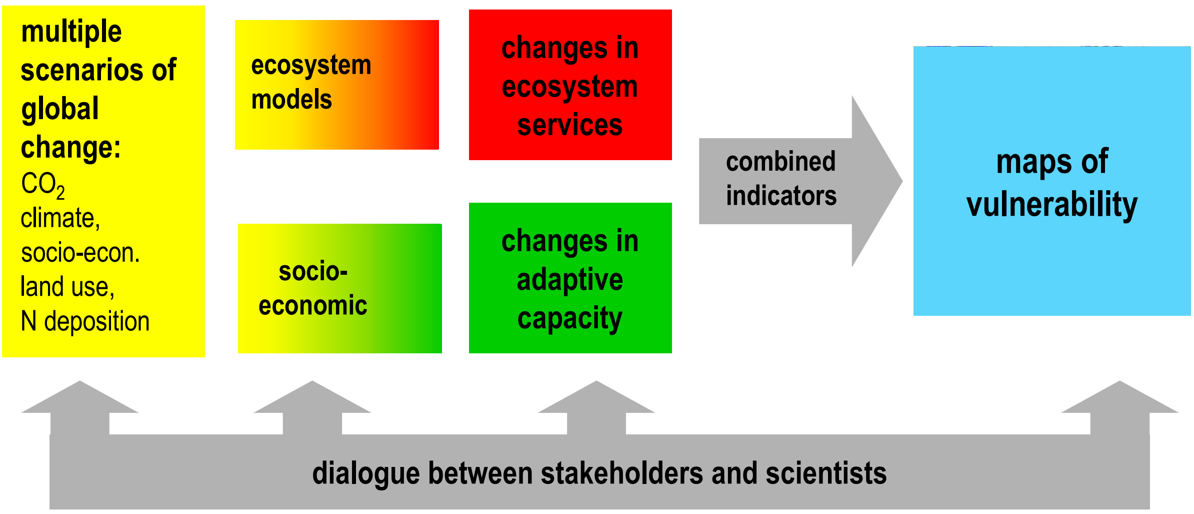

Figure 1. Schematic overview of the ATEAM vulnerability assessment framework. The basic elements are: multiple scenarios of global change (yellow box), translation into potential impacts (red box) and adaptive capacity changes (green box), combination into vulnerability maps (blue box), continuous stakeholder dialogue (grey box).

An overview of the steps taken in the ATEAM vulnerability assessment is depicted in Figure 1 (please note: all other figures are appended in Annex 3). To quantify *exposure* (yellow box, Figure 1) we produced a consistent set of multiple, spatially explicit global change scenarios. Projection of socio-economic and biophysical variables to the next century cover a range of possible futures, without assigning probabilities or likelihood to any individual scenario. To deal with this unknown uncertainty, we based our global change projections on a range of coarse narratives, the so-called marker scenarios, or

[7] Ecosystem services are the conditions and processes through which ecosystems, and the organisms that make them up, sustain and fulfill human life.

IPCC Special Report of Emission Scenarios (SRES) A1f, A2, B1 and B2. We used four different general circulation models to simulate possible climatic changes resulting from these four emission scenarios. We then developed a set of land use and nitrogen deposition scenarios that are linked to the climate scenarios and the socio-economics derived from the SRES storylines. This resulted in a consistent set of scenarios at high spatial resolution for the main global change drivers in Europe (10' x 10' grid resolution over EU15 plus Norway and Switzerland, baseline 1990, future time slices 2020, 2050, 2080).

Europe's managed ecosystems are sensitive to the exposure to these environmental changes. The resulting *potential impacts* (red box, Figure 1) are changes in ecosystem service supply. Humans can be vulnerable to such potential impacts because they rely on ecosystem services. In ATEAM, we model potential impacts using the input scenarios of global change and a range of state-of-the-art ecosystem models that represent the sensitivity of the human-environment system. The ecosystem services considered in the ATEAM project are listed in Table 1. In a stakeholder-guided process we selected a range of indicators for ecosystem services that are related to the sectors agriculture, forestry, carbon storage and energy, water, biodiversity and nature conservation, and mountains[8]. Different ecosystem modelling techniques are used for different sectors and environments, but all ecosystem models, use the same input scenarios, i.e. climate change scenarios, land use change scenarios, and, in some cases, nitrogen deposition scenarios.

To obtain a dimension of the third element of vulnerability, *adaptive capacity* (green box, Figure 1), we developed a spatially explicit and quantitative generic index of adaptive capacity (macro-scale: province level). This index is based on six determinants which were identified by the IPCC Third Assessment Report: power, flexibility, freedom, motivation, knowledge and urgency. For these determinants we selected twelve indicators such as gross domestic product, female activity rate, age structure, literacy index and urbanisation. We used projections of socio-economic variables (gross domestic product and population) and regression analysis with historic data of the indicators to obtain future projections. Fuzzy inference rules were then applied to aggregate the individual indicator values into one generic measure of adaptive capacity per spatial unit. The resulting generic index captures one of many dimensions of adaptive capacity. Elements of adaptive capacity furthermore enter the assessment with the land use scenarios (which consider assumptions about decision-making in a socio-economic and policy context) as well as with those ecosystem models that include human management (e.g. agricultural and forestry models).

How were these elements (exposure and sensitivity, resulting potential impacts and adaptive capacity) integrated into *maps of vulnerability* (blue box, Figure 1)? Empirical and theoretical evidence of how potential impacts and adaptive capacity can be combined into measures of vulnerability is very limited. Therefore, we created a visual combination of these elements without quantifying a specific relationship. The resulting maps illustrate vulnerability in terms of negative potential impacts and limited adaptive capacity. All results are made available to stakeholders in form of a digital atlas (spatially and temporal explicit maps of Europe) of exposures, potential impacts, adaptive capacity and a dimension of vulnerability. This tool allows comparison of scenarios, time slices and regions for each ecosystem service indicator. The maps are accompanied by careful documentation of the underlying assumptions and limitations of the approach. This digital atlas of Europe adds to the basis for discussion between different stakeholders and policy makers, thereby facilitating sustainable management of Europe's natural resources under global change.

Stakeholders were involved in the project from the very beginning for a more appropriate assessment of vulnerability (grey bar, Figure 1). In a number of workshops and through other interactions we discussed our approach with stakeholders from private sectors and with policy makers. The general objective of this dialogue was to facilitate a more appropriate assessments of ecosystem vulnerability, i.e. to

[8] "Mountains" is a type of environment, rather than a sector. Due to the unique nature of mountain system, we have nevertheless considered mountains in particular, focusing especially on mountain ecosystem services to the tourism sector.

produce results that would adequately inform the decision making of stakeholders. In particular, the aims of the stakeholder dialogue were to (1) identify indicators of changes in ecosystem services; (2) settle useful scales and units at which these indicators should be measured or modelled; (3) discuss thresholds for these indicators that represent limits outside which the adaptive capacity of the sectors is exceeded; and (4) present and discuss results as well as the format they are presented in (clarity of maps, graphs, etc).

In the following sections we will describe the methodological approach taken in each step depicted in Figure 1 in more detail and present the main scientific achievements made, and the deliverables obtained. All Figures but Figure 1 are appended in Annex 3.

Table 1. Sectors, ecosystem services they rely on and indicators for these ecosystem services that were chosen together with stakeholders.

Sector	Service	Indicator
Agriculture	Food & fibre production Soil fertility maintenance Bioenergy production	Agricultural land area (Farmer livelihood) Soil organic carbon content Nitrate leaching Suitability of crops Biomass energy yield
Forestry	Wood production Recreation Sense of place	Forest area Tree productivity: growing stock, increment, age class distribution Tree species suitability
Carbon storage	Climate protection	Net biome exchange[9] Carbon off-set by fossil fuel substitution[10]
Water	Water supply (irrigation, hydropower, domestic and industrial use) Drought & flood prevention	Runoff quantity Runoff seasonality Water resources per capity "Drought runoff"[11] "Flood runoff"[12]
Biodiversity and nature conservation	Beauty Life support processes (e.g. pollination)	Species richness and turnover (plants, mammals, birds, reptiles, amphibian) Shifts in suitable habitats
Mountains	Tourism (e.g. winter sports) Recreation	Elevation of reliable snow cover Number of heat days

6.2.1 Scenarios of global change (WP3 and 4)

6.2.1.1 Socio-economic and emission scenarios

The scenario development is based on the Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic and Swart, 2000). Contrary to earlier scenarios, the SRES approach centred on narratives (or storylines). The scenario assumptions are described in a consistent qualitative way by summarising two major dimensions. The first major dimension focuses on 'material consumption' (A) versus 'sustainability, equity and environment' (B). The

[9] Net biome exchange (NBE) = the net flux of carbon from the terrestrial system to the atmosphere, which is determined by net primary production (net carbon uptake by the plants), and carbon losses due to soil heterotrophic respiration, fire, harvesting, and land use change.

[10] Carbon offset by fossil fuel substitution = The difference between the carbon dioxide that would have been released had fossil fuels been used and the carbon dioxide released when biomass energy is used.

[11] "Drought runoff" = The annual runoff that is exceeded in nine years out of ten.

[12] "Flood runoff" = The mean maximum monthly runoff.

second major dimension distinguishes 'globalisation' (1) versus 'regionalisation' (2). The narratives specified typical aspects, processes and their dynamics for each of the four quadrants identified by these dimensions (A1, B1, A2 and B2). The A1 scenario was further elaborated by assuming different combinations of fuels and technology development to satisfy energy demand. Of these A1 sub-scenarios we consider only the A1f scenario in the ATEAM project, where the energy system remains dominated by fossil fuels. The section *Land use change scenarios* below gives a more detailed description of the storylines, while a full description is presented in detail by Nakícenovíc et al. (2000). The SRES storylines drive the climate change scenarios (through emissions scenarios) as well as land use change (through the different socio-economic development pathways). One of the strengths of using the SRES framework is that the assumed socio-economic changes relate directly to climate change through the SRES emissions scenarios, and to land use changes through socio-economic measures, such as demand and technology assumptions. Thus, a range of internally-consistent, quantitative scenarios of coupled socio-economic and climate changes were developed. The first step in quantifying the narratives was to describe each of the four SRES worlds in terms of single time-dependent scenarios of atmospheric greenhouse gas concentration (Figure 2, this and all further figures are appended in Annex 3). This was done using the integrated assessment model IMAGE 2.2 (IMAGE team, 2001). The A1f socio-economic scenario results in the highest emissions and concentrations of carbon dioxide, followed by A2, B2 and finally B1 (Figure 2).

6.2.1.2 Climate change scenarios

Climate change scenarios for monthly values of five different climatic variables (monthly temperature, diurnal temperature range, precipitation, vapour pressure and cloud cover) were created for all 16 combinations of four SRES emissions scenarios (A1f, A2, B1, B2, see above) and four general circulation models (GCMs; PCM, CGCM2, CSIRO2, HadCM3), using GCM outputs from the IPCC Data Distribution Centre. The results were subsequently downscaled from 0.5°x0.5° to 10'x10' resolution. The climate scenarios of the 21st century replicate observed month-to-month, inter-annual and multi-decadal climate variability of the detrended 20th century climate. The climate data used in this study are the European observed climate 1901-2000, 16 climate scenarios for 2001-2100, and a single 'control' scenario of unforced climate (1901-2100) based on the detrended 1901-2000 historical record. The full method is described in Mitchell at al. (2004). The scenarios are known as TYN SC 1.0 and are publicly available (http://www.cru.uea.ac.uk/). Priority scenarios were identified to allow a reduced analysis because resources were limiting (Table 2).

Table 2 The complete set of climate change scenarios combining different emissions scenarios and GCMs. The table also indicates the recommendation for priority application. *High* means all modelling groups were asked to apply these scenarios, *Medium* are strongly recommended to be used if possible, and *Low* are not mandatory, but are desirable if computational facilities and time allow.

	PCM	CGCM2	CSIRO2	HadCM3
A1f	low	low	low	high
A2	high	medium	medium	high
B2	low	low	low	high
B1	medium	low	low	high

We discovered two problems with this initial climate input data set which were solved within the project (thus our final project dataset differs from the dataset TYN SC 1.0 available at http://www.cru.uea.ac.uk/). The first problem was the lack of inter-annual variability in cloud cover and diurnal temperature ranges between the year 1901 and 1950 in the Mediterranean region. The reason for this is the lack of observed data for cloud cover and diurnal temperature data in the first half of the 20th century (Mitchell et al. 2004). Consequently the problem also arose for the period 2001 – 2050, since de-trended observed 20th century inter-annual variability was used to generate the 21st century scenario data. We solved the problem by using the 1951-2000 inter-annual variability twice for scenario generation 2001 – 2100 in the Mediterranean. All climate parameters were then re-calculated to keep consistency in the data set.

The second problem was the vapour pressure data in the climate input scenarios. The general circulation model (GCM) HadCM3 output showed no variability over the 21st century, and the GCMs CGCM2 and PCM output showed unrealistic spatial variability over Europe. The GCM CSIRO2 output did not contain vapour pressure data. So that in the CSIRO2 set of scenarios the data on vapour pressure were calculated from temperatures with the Magnus equation (Mitchell et al. 2004). Since this approach worked well for the CSIRO2 output in temperate and boreal climates, we decided to use the Magnus equation to obtain more realistic vapour pressure data in all climate scenarios. The Magnus equation assumes minimum temperature to be equivalent to dew point temperature. To improve data quality for drier areas, such as the Mediterranean where the air is not saturated with water at minimum temperature, we re-calculated dew point temperatures using an empirical equation described in Kimball et al. 1997. The input parameters for this equation are minimum and mean temperature, annual precipitation and daily potential evapotranspiration (PET). PET was calculated with the bioclimatic module of the LPJ-model (Sitch et al. 2003, Gerten et al. 2004). Then vapour pressure data of all 16 climate scenarios were recalculated using modified dew-point temperatures and the Magnus equation. This approach improved the consistency between climate parameters but does not reflect potential changes in the relationship between the parameters due to climate change. Comparing the calculated data with the CRU climatology which is based on observed values demonstrated that empirical equation after Kimball et al. 1997 significantly improved the quality of the calculated vapour pressure data.

Multiple scenario climate analyses (Figure 3) demonstrate the trends and uncertainties in projections of climate change in Europe. Temperatures (Figure 3A) show high variation but a clear trend towards a warmer climate in all projections. To compare the sensitivity of the different GCMs to the same forcing, i.e. the same emission scenario, we look at the A2 scenario for mean European temperature and compare the average temperature over the last decade of this century (2091-2100) to the last decade of the previous century (1991-2000). The GCM PCM projects the lowest temperature increase for A2 of 3.0°C (A2-PCM), followed by 4.0 and 4.7°C (A2-CGCM2 and A2-CSIRO2 respectively) to 5.2°C (A2-HadCM3, data not shown in Figure), showing that the sensitivity of the GCMs is different, even if they all agreed on a considerable increase in average European temperature. Looking at the same decades (2091-2100 compared to 1991-2000) we compared the consequence of different emission scenarios for one GCM, namely HadCM3. The emission scenario B1 leads to the most modest temperature increase of 2.9°C (B1-HadCM3), followed by the B2 scenario with 3.4°C (B2-HadCM3), and the A2 scenario (5.2°C A2-HadCM3). The A1f scenario results in the highest average temperature increase of 6.2 °C (A1f-HadCM3, data not shown in Figure).

Regional variation between the results of the climate models is considerable. Figure 4 shows the regional differences between the annual average temperature within Europe between the different climate models for the emission scenario A2. The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

Changes in precipitation are more complex. Whether the projected trends in precipitation are positive or negative depends on the season, the emission scenario, the general circulation model (Figure 3B) and on the region within Europe (Figure 5). Figure 5 shows the regional differences between the annual average precipitation within Europe between the different climate models for the emission scenario A2. Again the relative spatial pattern projected by each climate model remains the same and only the size of the anomaly varies between the emission scenarios and the maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

The variation in temperature and precipitation between scenarios and the variation between the seasons increase significantly in the second half of the 21st century. The variations between the climate models is different between the scenarios. For the high emission scenario A1f, the variation between climate models is approximately equally high as the variation between climate projection for all other emission scenarios (Figure 3).

A Tyndall working paper on the methodology and results has been published by Mitchell et al.(2004) and will be split into two parts for submission to peer-reviewed journals. Furthermore, the paper by Erhard et al. which is currently being prepared for the ATEAM special issue will deal with the climate scenarios in some detail (see Annex 2).

6.2.1.3 Land use change scenarios

Future land uses were constructed for the high priority scenarios given in Table 2 and for A2 CGCM2 and A2 CSIRO2 (medium priority), based on an interpretation of the four SRES marker scenarios. The interpretation was undertaken by first defining the range of drivers that will affect different land use types within Europe: urban, agriculture (cropland, grassland and biofuels), forestry and designated areas.

The approach recognises three levels in the derivation of land use scenarios that move from qualitative descriptions of global socio-economic storylines, over European sector driving forces (see Table 3), to quantitative projections of regional land use change. For each land use category the methodology broadly followed the same steps. First an assessment was made of the total area requirement (quantity) of each land use, as a function of changes in the relevant drivers. This was based on outputs from the global scale IMAGE 2.2 Integrated Assessment Model on commodity demands at the European scale (IMAGE team, 2001). Second, scenario-specific spatial allocation rules were developed and applied to locate these land use quantities in geographic space across Europe. Third and finally, the scenarios of the broad land use types were post-processed to maintain the land use constant in designated areas (for conservation or recreation goals). This approach was implemented using a range of techniques that were specific to each land use, including reviews of the literature, expert judgement, and modelling. Widespread consultation was undertaken with other experts in this field, as well as with stakeholders. For a detailed description of the methodology refer to Rounsevell et al. 2003. (A summary of the European land use change scenarios – version 2.0, pp. 38. Report, see Annex 2). The land use scenarios reflect changes both in the physical environment (climate change) with concurrent changes in socio-economic factors. The result is an original dataset and maps of Europe for each scenario and for each land use type.

European level sectoral driving forces

Sector-specific driving forces for Europe for each land use type were developed from the global level driving forces taken from IMAGE 2.2 (see above). This was based on an interpretation of the SRES narrative storylines for the European region using, where appropriate, knowledge of past and present European and national policy. For some land use types (e.g. forestry, protected areas), it was necessary to identify distinct regional trends in driving forces based on countries or country groups. The regional trends themselves may also differ between scenarios. An important aspect of the European level qualitative descriptions was to provide a check of internal consistency between each of the land use sectors and storylines. In this way, the assumptions that were used, for example, for urban land use were not in conflict with those for agriculture. A summary of the European level qualitative descriptions is given in Table 3.

Table 3. Summary of scenarios for cross-cutting drivers at the European scale

A1 Europe	
Economy	Very rapid economic growth and convergence between regions. European income inequalities eradicated. Material consumption and increases in income/capital lead to increased use of natural resources
Population	European fertility rates reach 1.7 with a slight increase in population to 2050 then a decrease
Technology	High investments in technology and high rates of innovation
Institutions and government	Governments are weak with a strong commitment to market based solutions. International co-operation. Stable political and social climate, with good health care and education. Self-sufficiency not an issue; free trade emphasised.
Rural development	Focus on centres and international connections, rural development not a focus area. Increased affluence has "spill-over" effects on rural and remote areas.
Recreation, tourism	Increase in recreation areas close to urban centres, wilderness areas are less attractive. Increases in beach resorts and locations with built facilities rather than eco-tourism
Spatial planning	Convergence of planning policy and less restrictions
EU enlargement	Proceeds rapidly
A2 Europe	
Economy	Moderate GDP growth; slower than A1. Economic development is regionally-oriented and uneven. The income gap between developed and developing countries does not narrow.
Population	European fertility rates reach 2.1 resulting in a steady increase in the population
Technology	Slower than in A1 and more heterogeneous. Technology transfer and diffusion slower
Institutions and government	Self-reliance of regions, less mobility of people, ideas and capital. Social and political institutions diversify. Central national governments weak, "markets first" approach. A more protectionist Europe compared to the present which could mean a stronger EU.
Rural development	Rural development results as a by-product of the stress on regional self-reliance
Recreation, tourism	Tourism decreases, but recreation increases with population increases. Demand for near urban recreation areas increases, but areas distant to centres are also used for recreation by a dispersed population. Built facilities are valued, wilderness areas are less popular.
Spatial planning	Heterogeneity of planning policy
EU enlargement	Stops or proceeds very slowly
B1 Europe	
Economy	A convergent world with global solutions to economic, social and environmental sustainability. Progress toward international and national income equality. Affluent with moderate GDP growth rates.
Population	European fertility rates reach 1.7 with slight population increase by 2050 then a decrease
Technology	Rapid technological change
Institutions and government	Central governments strong with a high level of regulation. International institutions and cooperation central.
Rural development	Rural development a key issue: equitable income distribution and development a priority
Recreation, tourism	Tourism decreases, but recreation increases, both near to urban centres and in remote areas
Spatial planning	Homogeneous, restrictive policies with high level of regulation
EU enlargement	Proceeds at a moderate rate
B2 Europe	
Economy	Local solutions to economic, social and environmental sustainability. Rate of development and GDP growth rate is generally low. International income differences decrease at a slower rate than in A1, B1. Education and welfare programmes are pursued.
Population	Population is stable
Technology	Technological change and innovation unevenly distributed
Institutions and government	Local self-reliance and strong communities. Decision making is at local/regional level and central government is weak. Citizen participation in decision making is high and government policies and business strategies are influenced by public participation.
Rural development	Increases because of emphasis on self-reliance and local products
Recreation, tourism	Tourism decreases. Recreation increases nearer to urban areas and rural villages with access by public transportation.
Spatial planning	Restrictive and heterogeneous policy
EU enlargement	Stops

Regional level land use specific quantification of scenarios

At the regional level, changes in land use areas for each land use type were estimated. One of the important issues when dealing with land use change in Europe is that these changes will also be affected by events outside of Europe. This is especially important in relation to trends in global trade. Thus, land use in Europe reflects not only demand (and supply) of the internal market, but also the demand for land based goods (e.g. food, wood products) that derive from outside of Europe. Estimation of these demands required the use of an integrated assessment model that simulates global trade patterns. In the work reported here, results from the IMAGE 2.2 model were used for this purpose. IMAGE provides for OECD[13] Europe (and for each of the considered scenarios) demands for agricultural and forestry products (including animal products, food crops, grass and fodder species, wood and biofuel crops). These demands were used both directly in the quantitative assessments for agriculture, and as a cross-check for the forestry land use change areas.

Urban land use

The following driving forces of urban land use change were identified: population, economics, accessibility of a location with respect to the transport network, the distance to large cities, the distance to medium sized cities and the distance to small cities. The city distances are distinguished according to city size in order to reflect the different impacts and attractiveness of a larger or a smaller city, and in order to simulate the different patterns of sub-urbanisation and counter-urbanisation processes. For each of the driving forces, indicators were chosen or calculated that were applied to an empirical-statistical model integrating theory and empirical data on urban land use. The results for each scenario show alternative patterns of future urban distributions, diffuse or concentrated, with larger increases in urbanisation close to large cities, or in rural areas.

Protected areas

Whilst the location of protected areas may change, it is assumed that the land use within a protected area will not change from the baseline, whatever the land use type and whatever the scenario.

The main driving force for protected areas is European and national policy for nature conservation. Other driving forces include policies for agriculture, forestry and spatial planning, as well as the demand for (green) recreation and tourism. An assumption is made that for all scenarios 20% of the area of Europe will have been designated as protected by 2080. Whilst the amount of new protected areas is the same for all scenarios, this target is assumed to be reached for different reasons: the economic scenarios require areas for recreation for a richer population, whereas the environmental scenarios have protection for conservation purposes. The allocation (location) of these protected areas between scenarios is assumed, however, to vary substantially. For the regional scenarios (A2, B2) the target is reached locally (country-level) and for the global scenarios (A1, B1) it is reached European-wide. Furthermore, for the A1 and A2 scenarios, economic priorities are assumed to lead to an opportunistic strategy for the location of new protected areas: their selection is based on the minimisation of opportunity costs. Basically, less valuable land is designated for protection. For the B1 and B2 scenarios, environmental priorities lead to a conservation strategy for the designation of new areas, and an assumption is made that new areas will maximise the conservation potential and biodiversity. Allocation rules are based, therefore, on the distribution of species and the need to conserve a maximum of species. For this purpose, biodiversity modelling results from WP2 were fed back into the land use modelling procedure.

Agriculture and biofuels

The driving forces for agricultural land use change are: world demand and supply, market intervention (through agricultural policy), rural development policy, environmental policy pressure, impact of EU

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[13] OECD = Organisation for Economic Co-operation and Development.

enlargement, resource competition (e.g. biofuels), the role of the WTO[14]. Scenarios of changes in agricultural areas for food crops (arable and permanent crops), grassland (meat and milk) and energy crops (biofuels) were estimated for each of the scenarios using a combination of simple supply-demand calculations at the NUTS2[15] level (based on the IMAGE2 demand figures) and scenario-specific spatial allocation rules. The basic idea was that land use areas will increase if demand increases, but decline if productivity also increases (due to technology or rises in atmospheric CO_2), i.e. meeting the same demand (production) requires less land. These changes were further modified by policy (intervention) assumptions within the scenarios and the regional effects of climate change (through latitude as a proxy for temperature). Biofuels are allocated after sufficient land has been allocated to food production (as recommended by the ATEAM stakeholders). The total biofuel areas are defined by IMAGE2.2, but their location and distribution are defined through spatial allocation rules. These rules are based on the location of agricultural areas (the suitability for plant growth) for each scenario and the proximity to urban centres (for efficient heat use). The allocation rules for biofuels were be updated in collaboration with agricultural modelling conducted in WP2.

Forest

The extent of forest in a country depends on climatic and other environmental causes and human activities. Population, economic growth, technological change, political-economic institutions and attitudes and beliefs have been identified as drivers of forest land use change and especially deforestation. In this study, the trends in forestry and forests of today were assumed to continue in the future until 2020. The changed circumstances described in the storylines were taken into consideration in scenarios for 2020–2050 and 2050–2100. Forests, however, have long rotation times in some regions, and trees planted today may only reach their harvesting age in 2080 or 2100. In the method reported here, percentage changes in forest area, and the location of these forests were estimated from an interpretation of the literature and the IMAGE2.0 forest product demand figures. This was undertaken for country groups with similar characteristics in terms of forest policy: Group 1 (Norway, Sweden, Finland), Group 2 (Austria, Switzerland), Group 3 (Portugal, Spain, Italy, Greece), Group 4 (France, Germany, Luxembourg, U.K.), Group 5 (Belgium, Ireland), and Group 6 (Denmark, Netherlands) (Kankaanpää and Carter, 2004 a,b).

Competition between land uses

There is only a finite amount of the Earth's surface available for land use activities, and the balance of different land use types within a geographic area reflects the competition between these different types. At any one location, a certain land use will have either a physical, economic or political advantage over other land uses and will, therefore, be more likely to be selected by a land user. When constructing land use change scenarios it is important, therefore, to take account of the competition for geographic space between the different land uses. To do this, we used a simple land use competition hierarchy. This is reflected in the following order of precedence:

Protected areas (green areas for recreation or conservation) > urban > agriculture > biofuels > commercial (unprotected) forests > not actively managed

Whilst within this scheme protected areas take precedence over all other land uses, their geographic extent is limited by demand, suitable locations (i.e. existing areas with conservation value) and the scenario assumptions (some scenarios may discourage protection for conservation). Urban land use is also limited by demand and land use planning policies, which are a function of the scenario. Biofuels rank below agriculture because food production is assumed to take precedence over energy production. Locations where no land use activities are possible (because of physical constraints) are assumed not

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[14] WTO = The World Trade Organisation.

[15] NUTS2 = Nomenclature des Units Territoriales Statistiques 2: regions or provinces within a country. There are around 500 NUTS2 units, as apposed to only 17 EU countries.

to be actively managed (i.e. they are 'abandoned' where previously actively used).

Summary of European land use trends

The general trends shown by the scenarios are of small increases in urban areas with different spatial patterns, large reductions in agricultural areas for food production (except for B1 and B2) partly compensated for by increases in bioenergy production, forests and areas protected for conservation and/or recreation with surplus land in the A1f and A2 scenarios. Figure 6 summarises these trends for the four SRES scenarios in 2080 (for HADCM3).

The large declines (of over 50%) in the surface areas of agricultural land use (especially grassland) for the A (economic) scenarios are caused primarily by the assumptions about the role of technological development. These area reductions are only partly compensated for by increasing biofuel production and forest land use, so that surplus land occurs within the A1f and A2 scenarios. It is unclear what could happen to these areas of surplus land, although it seems that continued urban expansion, recreational areas and forest land use would all be likely to take up at least some of the surplus. Declines in agricultural areas were less for the B (environmental) scenarios. This assumes, however, that the pressures toward declining agricultural areas are counterbalanced by policy mechanisms that seek to limit crop productivity. This could include measures to promote (a) extensification[16] or organic production (particularly consistent in the environmental scenarios), (b) the substitution of food production by energy production and the planting of trees, or an acceptance of overproduction (as with the current EU's CAP[17]).

A number of publications have already resulted from this work -- the papers referred to in the following are listed in Annex 2. One paper summarises especially the urban land use scenarios (Reginster and Rounsevell, 2004, submitted). Four papers summarise the approach developed for the agricultural scenarios and biofuels (Ewert et al, 2004, accepted; Ewert et al., 2004 submitted, Rounsevell et al. 2004, submitted, House et al., 2004, in preparation). Two papers summarise especially the forest policy analysis and the forest land use scenarios (Kankaanpää and Carter 2004 a,b). One paper in preparation will summarise the development of the scenarios for protected areas (Reginster, Araujo et al.2004). Synthesizing papers will also be submitted.

6.2.1.4 Nitrogen deposition scenarios

In collaboration with Maximilian Posch and Joseph Alcamo nitrous oxide (NOx)-deposition scenarios have been created for the different SRES scenarios in 5 year steps from 1970 to 2100. The scenarios were derived using a framework of two integrated models: RAINS (Regional Acidification Information and Simulation) and IMAGE (IMAGE team 2001). The main NOx emission source is fossil fuel combustion due to road transportation and power generation. The basic assumptions underlying the scenarios are that all European NOx-deposition stems from European emissions, and that its distribution across European countries does not change in the future (the 2000 shares are taken to distribute emissions). Emissions from power generation are based on current point sources; all others are homogeneously distributed over the countries. The methodology that was followed is described in detail in Alcamo et al. 2002. In short, European NOx emissions from the IMAGE model were used to determine the size of future sources. Then the EMEP/MSC-W (EMEP = Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe; MSC-W = Meteorological Synthesizing Centre-West) source-receptor calculations described regional transport of NOx in the atmosphere and local N-depositions (Lagrangian model). Finally each ATEAM grid cell was assigned the value of the corresponding EMEP grid (0.5° x 1.0° resolution).

These scenarios do not include deposition of reduced nitrogen compounds NHy, e.g. ammonium NH_3.

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[16] Extensification – The transition of a land cover or land use type associated with high intensity of use to a lower intensity of use (e.g. improved grassland to semi- natural cover).

[17] EU's CAP – The Common Agricultural Policy of the European Union.

Ammonium globally accounts for more than half of total nitrogen emission (Holland et al. 1999). The main ammonium source is domestic animal production. Especially for agricultural centres like the Netherlands and Belgium ammonium sources have to be taken into account in nitrogen deposition scenarios. WU is currently exploring the possibilities to include these sources in an advanced version of the ATEAM nitrogen deposition scenarios. Nevertheless, even our current nitrous oxide deposition scenarios are an important step forward in considering the global trend in eutrophication due to atmospheric deposition of nutrients when acknowledging this limitation.

Previously estimated nitrous oxide emissions available from EMEP and IIASA (IIASA - International Institute for Applied Systems Analysis, Laxenburg, Austria) are smaller, because they neglect background emissions from natural ecosystems and agriculture (Table 4). In regional comparison within Europe, emissions are estimated to be highest in Central Europe as well as in Ireland and Wales Figure 7).

Table 4. Comparison of ATEAM (from IMAGE) and IIASA European NOx emission scenarios.

Country	IMAGE emissions (kt NO_x)	EMEP/IIASA emissions (kt NO_x)
Austria	377	202
Belgium	599	321
Denmark	517	277
France	3548	1899
Germany	5056	2706
Italy	3621	1938
Luxemburg	43	23
Netherlands	1072	574
Portugal	592	317
Spain	2390	1279
Sweden	652	349
Others	15801	11182

6.2.1.5 Overview over the complete ATEAM global change input data set

To facilitate collaboration with other projects and institutions we have compiled an overview of the data sets available from ATEAM in Table 5.

Table 5. Overview over the complete ATEAM global change input data set.

Data Set	Source	Parameters and Classification
Climate	Climate data set (New et al. 2000, Mitchell et al. 2004)[1] Monthly observed climatology 1901 - 2000 16 monthly climate scenarios 2001 - 2100 4 SRES scenarios (A1fi, A2, B1, B2) 4 GCMs (HadCM3, PCM, CGCM2, CSIRO2)	Temperature, diurnal temperature range, precipitation, cloud cover, vapour pressure: Transition data 2001 - 2100 also with modified vapour pressure 10 and 30 year time slices 1990, 2020, 2050, 2080 (year is the last year of the time slice)
Atmospheric CO_2 concentration	"Post SRES Scenario Webpage" (http://crga.atmos.uiuc.edu/research/post-sres.html) "Mauna Loa CO_2 records" (Keeling & Whorf, 2002, http://cdiac.esd.ornl.gov/ndps/ndp001.html) IMAGE2.2 SRES scenario implementation data (RIVM 2001)	Annual atmospheric CO_2 concentration (ppmv) per SRES scenario (A1f, A2, B1, B2)
Nitrogen deposition	Posch 2002, Alcamo et al. 2002, IMAGE 2001	Mean annual NO_x and NH_y deposition per 10' x 10' grid-cell in 5 year time steps for 1970 - 2100 and per SRES scenario (A1fi, A2, B1, B2)
Soil properties	Global Soil Data Task (Global Soil Data Task, 2000)	Soil type, texture, physical, chemical parameters per soil unit and layer
Terrain	CRU elevation data set	Elevation 10' x 10'

	(http://www.cru.uea.ac.uk/~timm/grid/table.html) European HYDRO1k data (USGS EROS Data Center /Distributed Active Archive Center, http://edcdaac.usgs.gov/gtopo30/hydro/europe.html)	Elevation, slope, aspect, topographic index, flow direction, flow accumulation, watersheds, streams
Land cover	CORINE except Sweden, Croatia and Yugoslavia, Russia 250m x 250m (Corine 1997, BFS 2002) PELCOM, pan-European land-cover 1100m x 1100m (Mücher et al. 1999)	Urban areas, arable land, permanent crops, pastures, heterogeneous agricultural areas[2], forests, shrub and/or herbaceous vegetation associations, open spaces with little or no vegetation, inland wetlands, coastal wetlands, inland waters
Land use	IMAGE2.2 SRES scenario implementation data (RIVM, 2001) Forest species maps (Köble & Seufert, 2001) aggregated to Plant Functional Types (PFTs)	C3 grass, fodder, cereals other than rice or maize, rice, maize, pulses, roots & tubers, oil crops temperate needleaved evergreen, temperate broadleaved evergreen, temperate broadleaved summergreen, boreal needleleaved evergreen, boreal needleleaved summergreen, boreal broadleaved summergreen
Land use scenarios	Land-use change scenarios created by UCL (see this report work package WP 4 and Ewert et al. 2004 in press)	Change in arable land, grassland, forests, urban area, biofuels, surplus land, others projected for the time slices 2020, 2050, 2080 and the 4 SRES scenarios (A1f, A2, B1, B2)
Land use history	Historic land cover changes (Ramankutty & Foley, 1999) HYDE data set (Goldewijk, 2001) Forest area 1960-1994 (FAO, 2000; http://dataservice.eea.eu.int/dataservice/) FAO forest resource assessment 1948-2000 (Efidas, 2000; http://www.efi.fi/efidas/)	Change in arable land, grassland, forests, urban area, others in 10 years time steps from 1900 onwards
Socio-economic scenarios	Indicators for adaptive capacity: national data down-scaled to NUTS2[18] Region via urban area) (Klein et al., in prep.; http://www.ciesin.org/)	Inequality, telephone mainlines, number of physicians, enrolment (number of people attending higher education), GDP and population density per administrative region (NUTs level 2) for 2000, 2020, 2050, 2080 per SRES scenario (A1f, A2, B1, B2)

6.2.2 Modelling of ecosystem service supply (WP2)

We modelled potential impacts using the input scenarios of global change and a range of state-of-the-art ecosystem models that represent the sensitivity of the human-environment system. The ATEAM modelling framework consists of models for agricultural systems, for forest systems, for biogeochemistry and vegetation cover, for fire driven dynamics, for water catchments, for biodiversity, and for mountain ecosystems (Table 6). We have adapted the structure and content of these ecosystem models to optimise their use for vulnerability assessment at the regional scale for Europe. Where needed and possible, models were enhanced, recalibrated and modified, based on the outcomes of the testing of their performance. In the following we will report on potential impacts that were estimated using these models for European sectors.

[18] NUTS2 = Nomenclature des Units Territoriales Statistiques 2: regions or provinces within a country. There are around 500 NUTS2 units, as apposed to only 17 EU countries.

Table 6. Ecosystem models used in ATEAM to model changes in ecosystem services, listed per sector.

Sector	Model	Reference
Agriculture	Land use change scenario SUNDIAL ROTHC IMAGE (biofuel demand)	(Rounsevell et al. 2004 submitted) (Smith et al. 1996) (Coleman and Jenkinson 1996, Coleman et al. 1997) (IMAGE team 2001)
Forestry	GOTILWA+ EFISCEN	(Sabaté et al. 2002) (Nabuurs et al. 2000, Karjalainen et al. 2002)
Carbon storage	LPJ (biogeochemistry)	(Sitch et al. 2003, fire dynamics: Thonicke et al. 2001)
Water	Mac-pdm	(Arnell 1999, Arnell 2003)
Biodiversity and Nature Conservation	statistical niche modelling	(Araújo et al. 2002, Thuiller 2003)
Mountains	RHESsys (mountains)	(Band et al., 1993, Tague and Band 2001, Tague and Band, 2004)

6.2.2.1 Agriculture

The agricultural sector relies on ecosystem services such as food and fiber production, soil fertility maintenance, and biomass energy production. Global changes in Europe will impact these services, as indicated by potential impacts on a number of ecosystem service indicators that were identified together with stakeholders from the agricultural sector (see Table 1). During the 21st Century, agriculture will be radically altered. Climate change will mean that many areas become too hot or too dry to support agriculture. Changing world economies, and likely changes in the Common Agricultural Policy and the subsidies currently paid to farmers and land managers, will also mean that less land will be used for agriculture in the future (see also section *Land use change scenarios*). The impact of climate differs between different future climate scenarios and the impact of land use change also differs between future land management scenarios.

Soil organic carbon

Principal investigators: Pete Smith, Jo Smith & Martin Wattenbach in collaboration with ATEAM climate group, Sönke Zaehle and JRC-Ispra (Bob Jones, Roland Heiderer, Luca Montanerella)

It was our aim to examine how global changes would impact upon soil organic matter, important for maintaining soil fertility and important for locking up carbon that would otherwise be lost to the atmosphere as carbon dioxide (see Table 1). To examine the impact on soil organic matter (expressed in terms of soil carbon) we looked at changes in cropland and grassland soil carbon during the 20th and 21st Centuries using the Rothamsted Soil Carbon (RothC) model for the ATEAM grid (for A1f, A2, B1, B2 scenarios with HadCM3, and three additional GCMs[19] for the A2 scenario). We also used the best available soils data (European Soils Database), as well as outputs on potential evaopotranspiration (PET, water loss from the soil and the plant), and net primary production (NPP, plant growth) from the LPJ model[20]. We used a land use change reconstruction for the 20th Century and the future land use scenarios that are consistent with the climate scenarios (see above) from the ATEAM land use group. The model was used to examine the effects of climate only, climate including the effects on plant growth, and the combined effects of climate and land use change.

Looking at climate impacts alone, the decrease in soil carbon is significant for all scenarios but is most pronounced in the A1f scenario and least pronounced in the B1 scenario (Figure 8). Differences

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[19] GCM = general circulation models, coupled atmosphere/ocean-models to estimate climate change. resulting from greenhouse gas emissions

[20] The LPJ (Lund-Potsdam-Jena) Dynamic Global Vegetation Model. A model that uses input on climate, land use, soil and atmosphere to calculate vegetation growth.

between the different climate models were of a similar magnitude to the emission scenario differences, showing that the choices we make about socio-economic development contribute substantially to uncertainty (Figure 9). Including plant growth is shown to slow the decrease in soil carbon relative to climate only (Figure 10). However, land use change also has a pronounced effect. In some cases, land use change (from abandoning croplands) slows the decline in soil carbon such that it counteracts the loss induced by climate change (Figure 11).

Technological development also has the potential to slow the decrease in soil carbon (not shown), but this depends upon how much of the potential increase in net primary production (NPP, plant growth) due to technological improvements is translated into carbon inputs.

In terms of soil fertility in the future, then, climate change will tend to decrease soil carbon, but greater plant growth will slightly decrease this adverse effect. Land use changes during this century (particularly abandonment of agriculture) might partially counteract the adverse effect of climate change on soil carbon in some cases.

A number of papers to be submitted in peer-reviewed journals such as *Global Biogeochemical Cycles* are in preparation. Numerous presentations from this work have been given. All output is listed in Annex 2.

Biomass energy crop suitability

Principal investigators: Gill Tuck and Margaret Glendining

The work centered on determining the potential distributions of biomass energy (biofuel) crops in Europe, and how climate change would effect these distributions.

Twenty-seven actual or potential biofuel crops were selected from those already being grown in Europe, or those mentioned in literature as showing potential as biofuel crops (El Bassam, 1998). Simple rules were derived for each crop for suitable climate conditions and elevation, to determine their potential distribution in Europe. The climate conditions were based on minimum and maximum temperatures at various times of the year, and precipitation requirements (Bassam 1998; Russell & Wilson 1994; Russell 1990). No account was taken of soil type, slope, etc. All crops are assumed to be rain fed, and not protected from frost.

A suitability model was written to determine whether each crop could grow in each grid cell, based on the simple rules for climate and elevation. The output was used to produce maps of suitability using ESRI®ArcMap8.3 for each crop for the 1990 baseline and for climate scenarios of the time slices 2020, 2050 and 2080, using all four climate models (HadCM3, CSIRO2, PCM and CGCM) with the four emission scenarios, A1f, A2, B1 and B2. No account was taken of changing CO_2 concentrations, nor of changing likelihood of infections with pests and diseases resulting from climate change. The baseline maps were compared with maps of the regional distribution of ethanol, oil and biofuel crops (FAO 1996) and the FAO statistics of agricultural production (FAO 2002). Each crop was checked to ensure that all countries in Europe and N Africa listed as currently producing that crop were included in our baseline suitability maps. This is not an exhaustive check, as some crops are not grown in a country for economic or other reasons, other than climate. For example, hemp cultivation is prohibited in Germany, due to possible production of cannabis. However, the climatic conditions in Germany would allow the crop to be grown there (Bassam, 1998).

Table 7 (shown in Annex 3) summarises the percentage of total land area in Europe potentially suitable, in terms of climate and elevation only, for growing the 27 biofuel crops in 1990, grouped according to latitude (Figure 12 shows the latitudinal bands used). Table 7 also indicates the change in % land area with a suitable climate, due to climate change, in the 2020s, 2050s and 2080s, based on the HadCM3 A2 scenarios. There is a general trend for the potential distribution of many crops to move North, compared to potential cropping areas in 1990. One of the most extreme examples is soybean, which has a minimum monthly summer temperature requirement of 17°C. Currently only 25% of the land area in latitude 45-54 has a climate suitable for growing soybean. By 2020 this is predicted to increase to 60%. Many crops show an increase in potential areas of production in the 2020s which does not continue into the 2050s and 2080s – this may be due to a reduction in annual rainfall between 2020 and 2050 (for example, soybean, in latitude 45-54).

Currently the climate in latitude 65-71 is only suitable for a few potential biofuel crops (reed canary grass, linseed, short rotation coppice, barley, whole maize and Jerusalem artichoke). Climate change could allow a much wider range of crops to be grown here by the 2080s (Table 7), including rape, wheat, sugar beet, oats, rye and potato. Climate change could furthermore extend the suitable area of existing crops.

The climate predicted by HadCM3 in many areas of southern Europe (Latitude 35-44) is anticipated to be less suitable for growing nearly all biofuel crops by 2050, with the exception of olives and other crops with a high temperature requirement, and ability to withstand drought, e.g. groundnut, safflower and prickly pear (Table 7).

Figure 13 shows an example of the effect of the different scenarios, using output for sunflower, with simulated climate in 2020, 2050 and 2080 for the A1f, A2, B1 and B2 scenarios with HadCM3. Sunflower requires between 350 and 1500 mm of rain per year, with temperatures between 16 and 41°C March to September. In all scenarios sunflower could potentially be grown further North by the 2050s and 2080s than is currently the case, due to increased summer temperatures. The spread northwards is most pronounced with the A1f scenario, and least pronounced with the B2 scenario. All scenarios also predict a reduction in potential sunflower distribution in southern Europe, particularly in central Spain, due to summer drought. This effect again is most pronounced with the A1f scenario.

Figure 14 shows an example of the effect of different GCMs for short rotation coppice (SRC) using simulated climate in 2080 from HadCM3 and CSIRO2. SRC requires between 600 and 2000 mm of rain per year, with minimum monthly temperatures of 5°C between May and September. It can be seen that by 2080 both models predict that SRC potential production will move North compared to potential production in 1990, due to increasing summer temperatures. SCR will be restricted to Scandinavia, Northern Europe and the UK, and production will no longer be possible in Northern Spain, and much of Central Europe, due to a decline in annual precipitation. It is also clear that there are differences between the two GCMs, with CSIRO2-climate in Germany and Poland still suitable for SRC production in the 2080s, whereas HadCM3-climate is not suitable for SRC in these countries. In HadCM3-climate the reduction in annual precipitation in these countries over time is greater than in CSIRO2-climate.

In summary, we have derived maps of the potential distribution of 26 promising biofuel crops in Europe, based on simple rules for suitable climate conditions and elevation for each crop. We then studied the impact of climate change under different scenarios and from different GCMs on the potential future distribution of these crops. There is a general trend for crops to extend their range northwards due to increasing temperatures, with a reduced range in southern Europe, due to greater drought. These effects are greatest under the A1f scenario and by the 2080s, with differences between the different climate models (GCM).

The work is planned to be published in *Global Change Biology* (see Annex 2). The full set of suitability maps is available from the principal investigators.

Potential carbon offset by biomass energy use

Principal investigators: Jo House, Gill Tuck, Pete Smith, Mark Rounsevell (with Jeremy Woods, Imperial College)

When biomass energy products are used for energy production instead of fossil fuels, less carbon dioxide per unit energy produced is released. The difference between the carbon dioxide that would have been released had fossil fuels been used and the carbon dioxide released when biomass energy is used is called *carbon offset*. It is the amount of carbon dioxide saved when biomass energy are used to substitute fossil fuels. Biomass energy production and carbon offset values were calculated for a range of land use scenarios. Land area under different energy crop types was based on land area demand from the IMAGE model and crop suitability maps (see above). Geographical location of crops was implemented based on allocation rules. Yields of different crop types were derived from the LPJ model outputs. Yields for short rotation coppice (woody) and grass (*Miscanthus*) crops were based on published yields. Land energy conversion factors were based on published literature. Assumptions were made about increasing crop yields, energy conversion efficiencies and changing energy conversion capabilities. Energy production from forest and agricultural residues were also calculated.

This work will be published in paper to be submitted to a refereed journal (see Annex 2).

6.2.2.2 Forestry

Large scale impacts of climate and use change on forestry (regional level)

Principle investigators: Jeannette Meyer, Sergey Zudin, Jari Liski, Marcus Lindner, Sönke Zaehle, Ari Pussinen

The development of forest resources is affected by several factors, including tree species, age class distribution, soil properties, past and present forest management, climate, natural disturbances and land use change. The objective of the EFI contribution to ATEAM was to assess the impacts of changes in climate, land use, demand for forest products and forest management on the European forest sector using the European Forest Information Scenario model (EFISCEN).

EFISCEN is a large-scale forest scenario model that uses forest inventory data as input (Sallnäs 1990; Pussinen et al. 2001). EFISCEN can be used to produce projections of the possible future development of forests on a European, national or regional scale (Nabuurs et al. 1998; Päivinen et al. 1999; Nabuurs et al. 2001; Karjalainen et al. 2002). The inventory data used in this study cover almost 100 million hectares of forest available for wood supply and reflect the state of the forest around the mid-nineties in 15 countries: EU15 without Greece and Luxembourg, plus Norway and Switzerland. Greece and Luxembourg were not simulated due to the lack of suitable inventory data.

We used the seven ATEAM priority climate scenarios, together with the corresponding land use scenarios: the HadCM3 model with each of the four emission scenarios (A1f, A2, B1, B2), and the CGCM2, CSIRO2 and PCM models with the A2 emission scenario. In addition, demand scenarios were derived for the same storylines from the IMAGE scenario documentation (Image Team 2001). Current (2000) wood demand was scaled with demand projections from IMAGE 2.2 (Image Team 2001) for each of the four emission scenarios, assuming that the relative change in felling levels would be constant throughout Europe. Wood demand increased strongly in the A1f scenario and, to a lesser extent, in the A2 scenario. In the B1 scenario, wood demand decreased, while it remained relatively constant in the B2 scenario.

We used relative forest cover change from the ATEAM land use scenarios to scale the current (2000) forest area available for wood supply in each of the EFISCEN regions. Assumptions about which tree species would be chosen for afforestation were based on the socio economic storyline and the demand projections. We assumed that coniferous species would be favoured in the A1f and A2 worlds, due to the limited environmental concern and high wood demand in both scenarios. We assumed that only autochthonous[21] tree species would be used for afforestation in the environmental scenarios, B1 and B2. Management regimes (age limits for thinnings and final fellings) were based on a country-level compilation of management guidelines. Forest management under these regimes is different in the different scenarios and depends on wood demand. When wood demand is high, management is intense (i.e. shorter rotation time length).

To incorporate climate change induced growth changes, we used net primary productivity (NPP) values

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[21] Autochthonous – “native”, species that originate where they occur.

provided by the Lund-Potsdam-Jena global dynamic vegetation model (LPJ) to scale inventory based stem growth in EFISCEN. This approach enabled us to utilize state-of-the-art information about forest resources and forest management in Europe together with scenarios of climate and land use that were consistent with other results of the ATEAM project.

In order to quantify the effect of forest management, climate change and land use change, we ran the model using the four management scenarios with and without land use change (the latter separately for current climate and the climate change scenarios). Growing stock, increment, age-class distribution, and carbon stocks in above- and below-ground biomass were used as indicators to describe forest resource development in the 21st century.

For each scenario, climate change resulted in increased forest growth, especially in Northern Europe. The adverse effect of increased summer drought in Southern Europe was mitigated by higher precipitation in spring and increased water use efficiency in response to the rising atmospheric CO_2 concentration. Figure 15 presents the development of annual net increment for current climate, climate change, and combined climate and land use change model runs. The climate change effect of increased forest growth was more pronounced for the A scenarios than for the B scenarios. Management proved to be crucial for the development of increment. When wood demand was high, as in the A1f and A2 scenarios, and therefore forests were managed intensively, increment remained relatively stable or decreased slightly. When wood demand was low, as in the B1 and to a lesser extent in the B2 scenario, forests were managed less intensively and annual increment decreased drastically. The impact of land use change on increment varied substantially between the scenarios, depending on the extent of forest area change. In A1f, forest area remained almost unaltered, and therefore increment hardly changed when land use change was implemented. In B2, forest area increased by 32% between 2000 and 2100, and consequently increment was much higher in model runs with land use change than in those without.

The share of increment removed from the forest increased from 59% in 2000 to 118% in 2100 for the A1f scenario, and to about 97% in the A2 scenarios. In A1f, removals exceeded increment from the 2080s onwards. There was substantial regional variation in the share of the increment that was removed from the forest. In most parts of central and Southern Europe, removals exceeded the increment in 2100 in the A1 and A2 scenarios. In B1 and B2, removals remained smaller than the increment in all studied countries. In the B1 scenario, the share of increment removed from the forest decreased over time, while it remained relatively stable in the B2 scenario. Hence, in the A1f and A2 scenarios, wood demand exceeded potential felling, particularly in the second half of the 21st century, while in the B1 and B2 scenarios future wood demand can be satisfied.

Growing stock was larger in 2100 than in 2000 in all scenarios, despite the high felling levels and the decrease in increment in some of the scenarios during the last decades of the 21st century. The increase was highest under the HadCM3 B1 scenario, and lowest under the HadCM3 A1f scenario. The variation between the four GCMs was very small, while the SRES scenarios spanned a broad range, from 24800 million cubic meters in 2100 under the A1f scenario assumptions, to 41600 million cubic meters for the B1 scenario. For the A1f scenario, growing stock decreased from the 2080s onwards, because felling exceeded net annual increment during that period (see above). For all A2 scenarios, total growing stock was still slightly increasing at the end of the 21st century.

Figure 16 compares how management, climate and land use change impact on the change in growing stock between 2000 and 2100. As the difference between the four GCMs was very small, we included only the HadCM3 scenarios in this analysis. The majority of variation between the level of increase was explained by differences in forest management, caused by varying demand for wood. When climate change was included, growing stock increased additionally by 18% (B1) to 24% (A2). Land use change accounted for 3%, 14%, 21% and 34% of the increase in growing stock for the A1f, A2, B1 and B2 scenarios, respectively.

The amount of carbon stored in managed forests is an important part of the total amount of carbon stored in Europe's terrestrial biosphere (see next section *Carbon Storage*) Carbon stocks in trees increased from 2000 to 2100 by between 76% (HadCM3 A1f) and 176% (HadCM3 B1), reflecting the changes in growing stock. The carbon sink in trees remained at the present level in the B1 and B2 scenarios. In the A1f and A2 scenarios, carbon sink capacity started to decrease around 2050 and, in the A1f scenario with HadCM3 climate, trees turned into a carbon source in 2080. Carbon stock changes in forest soils under land use change scenarios could not be assessed with the current model version. Without land use change, carbon stocks in soils increased by 19 – 25% between 2000 and 2100, both for the current climate model runs, and for the simulations with climate change.

Main conclusions for forestry results on the regional level

In general, all investigated climate scenarios increased forest growth throughout Europe. Growing stock increased throughout the 21st century except for the A1f scenario, where high felling levels caused a decrease in growing stock from 2080 onwards. In the A1f and A2 scenarios, the timber demand could not be satisfied during the second half of the 21st century. It should be noted, however, that our study did not consider trade flows within Europe. Despite of the strong increase in felling levels in the A1f scenario, in some parts of Europe the full felling potential was not reached. Such areas have the potential to increase felling and to export forest products. Moreover, changes in forest management guidelines could increase the supply, because the faster forest growth in a changing climate allows shorter rotation lengths. Afforestation measures have the potential to increase growing stock and annual increment in the long run, but large areas would be needed to obtain significant effects.

Management had a greater influence on the development of growing stock than climate or land use change. Depending on the scenario, management accounted for 60 – 80% of the stock change between the years 2000 and 2100, climate change explained 10 – 30% of the difference, and land use change had the smallest impact of 5 – 22%. Forest productivity also depended greatly on management. When forest resources were not fully utilised, the age-class distribution shifted towards old and unproductive forests, while intensive, sustainable forest management kept the net annual increment at a high level.

Except for the A1f scenario, total forest carbon stocks in managed forests increased over time all over Europe. In A1f, forests turned into a carbon source in 2080, due to the decrease in growing stock caused by the high felling level. Climate change slightly increased soil carbon decomposition in six out of seven scenarios, but the magnitude was negligible compared to the management induced increase in soil C storage.

The results summarized here are going to be submitted to Global Change Biology. Several other papers related to this work have already been published or are in preparation for peer-reviewed journals and conference proceedings (see Annex 2).

Impacts on specific forest tree species

Principle investigators: Santi Sabaté, Eduard Pla, Anabel Sánchez, Jordi Vayreda and Carlos Gracia

The CREAF efforts were oriented to apply the GOTILWA+ model (http://www.creaf.uab.es/gotilwa+/) to the whole European grid. This was possible connecting the model to an extensive relational database of territorial structure with a 10'x10' resolution. This data base provides the model with all the necessary information to run in each pixel (forest cover, dominant species (plant functional type), soil characteristics, forest structure and eco-physiology, type of management) and, it also provides, at the same level of detail, 100 years climatic series for the different climate change scenarios.

In general, GOTILWA+ simulations of wood production and wood yield for the whole of Europe support the results obtained for the pan-European EFISCEN simulations. The model further allowed to focus in on specific species that are typical for the Mediterranean region. Figure 17 shows climate change effects on wood production in all the Mediterranean pixels occupied by the pine species *Pinus sylvestris* (Scots pine), *P. halepensis* (Aleppo pine) and *P. pinaster* (Maritime pine). In relation to baseline series, climate change scenarios present an initial increase in wood production but this tendency decreases at the end of the series. In some cases, the values of different series converge. In the case of *Pinus pinaster*, the series corresponding to climate change become lower than the baseline at the end of the simulation. The lowest values for this variable are found in *Pinus halepensis* simulations. Thus, in spite of the overall positive effects of climate change on wood production some species will be affected negatively, especially in the longer term in the Mediterranean. In Mediterranean and Southern regions the conditions of increasing temperature and, in certain areas, a decrease of precipitation determines a generalized decrease of the soil water available especially marked in southern zones of Europe. This is accompanied by an increase of the evapotranspiration processes (water use). In fact, simulations for specific species indicate that in some regions tree mortality may go up as an effect of this climate change. This effect was mainly simulated in Southern regions where forests are at the edge of their bio-geographical distribution.

Important research challenges to further explore potential impacts on tree growth in the Mediterranean and the rest of Europe are to better introduce interactions between direct effects of atmospheric carbon dioxide concentrations and other environmental constraints, as well as the interactions with soil processes and the flow of nutrients.

Two papers from this work are underway in the Proceedings of the Spanish Association for Forestry Sciences *Cuadernos de la Sociedad Española de Ciencias Forestales* (see Annex 2).

6.2.2.3 Carbon Storage

European terrestrial carbon balance

Principal investigators: M.T. Sykes, P. Morales, B. Smith (Department of Physical Geography & Ecosystems Analysis, Lund University), I.C. Prentice (Department of Earth Sciences, University of Bristol), J. House (Max Planck Institute for Biogeochemistry), W. Cramer, A. Bondeau, S. Sitch, S. Zaehle, D. Schröter, Fred Hattermann, Jürgen Kropp (Potsdam Institute for Climate Impact Research, PIK).

The Kyoto Protocol specified legally binding commitments by most industrialized countries to reduce their collective greenhouse gas (GHG) emissions. With the goal of reaching these targets at the lowest possible cost, the protocol created two flexibility mechanisms, GHG emissions trading and the Clean Development Mechanism (CDM). Important CDM strategies are carbon dioxide emission reduction by using alternative energy sources (e.g. hydropower and biomass), as well as by *maintaining important carbon sinks like soil organic matter and forests*. Within this political framework, net terrestrial carbon storage becomes an ecosystem service. Information on European carbon storage is useful to politicians in negotiations regarding the Kyoto process. Additionally, a range of stakeholders are interested in estimates of net carbon storage potential of their land. Depending on European Union (EU) mitigation policies, owners or managers of land may receive credits for land use and management that maintains or increases carbon storage.

Throughout the project we have collaborated with stakeholders interested in carbon storage, which included representatives of national and European forest owners, land owners, agricultural producers, paper industry, consultancy groups to the paper industry, farm management agencies, consultancy groups to environmental engineers, environmental finance companies, national and European representatives of environmental agencies, as well as biomass energy companies and foundations (see section *Stakeholder Dialogue*). These stakeholders expressed an interest in the carbon storage potential of forests. Besides the direct commercial interest in carbon storage, stakeholders also mentioned the potential side effects of increasing the carbon storage in terrestrial biomass, such as enhanced recreational value of a landscape and possible positive impacts on water purification.

The ecosystem service carbon storage is indicated by the variable net biome exchange (NBE), which is provided by the dynamic global vegetation model LPJ (Sitch et al. 2003). The NBE of an area is determined by net primary production (NPP, net carbon uptake by the plants), and carbon losses due to soil heterotrophic respiration, fire, harvesting, and land use change. Net carbon storage is the integral of

NBE (sources plus sinks) over time. Net carbon uptake (negative NBE) is valued as an ecosystem service to reduce carbon dioxide concentrations in the atmosphere. Net carbon emission (positive NBE) is regarded as an ecosystem disservice, adding to the atmospheric carbon dioxide concentration. The amounts of carbon that can be efficiently stored in terrestrial vegetation over long periods of time need to be considered in terms of absolute numbers, in relation to other pools and fluxes (atmospheric concentration, anthropogenic emissions, uptake by the oceans) and within the political context.

A modified version of LPJ was used to assess the effect of the ATEAM scenarios on the European carbon balance, representing the actual land cover and land cover dynamics. Based on land use data from remotely sensed sources (CORINE/PELCOM), and a reanalysis of historical trends of the land cover classes (FAO 2000, Ramankutty and Foley (1999)) each grid cell is subdivided into land cover classes of potential natural vegetation (standard LPJ), managed grasslands, a generic cropland scheme (Bondeau et al. in prep.), managed forest (Zaehle et al., in prep), and barren land. The model is spun up to equilibrium using the 10' CRU4-climatology (1901-1930 recycled), and reconstructed land use data from 1900. LPJ is then run in a transient mode with the 20th century 10' CRU climatology and the reconstructed land use, which is updated annually.

The results confirm that Europe's terrestrial biosphere currently acts as a sink, mainly due to carbon sequestration in expanding forest areas (e.g. Nabuurs et al. 2003). Although the size of the sink modelled with LPJ is notably smaller than estimated elsewhere (e.g. Janssens et al. 2003), the results are within the uncertainty bounds of these studies. In an experiment to estimate the effect of historic forest management changes on the increase in forest carbon stock we found a strong impact on the current carbon balance. However, the effect of historic forest management on future forest vegetation carbon is small compared to the effect of future climate, land use and forest management change.

The variation between climatic change derived from different GCMs was evaluated using different climate models driven with the same radiative forcing (the emission scenario A2). All model runs show an increasing sink strength up to the mid of the 21st century (Figure 18A, negative values denote fluxes into the terrestrial system, positive values denote fluxes out of the terrestrial system into the atmosphere). Thereafter, increased warming (mainly in winter) in Northern Europe enhances soil respiration more than net primary production in all scenarios , therefore decreasing the sink or even turning into a net carbon source towards the end of the century. In Southern Europe the climate models differ more strongly both in terms of warming and increase in drought stress. Particular mild and wet scenarios (PCM) lead to an increase in net carbon uptake, whereas hotter and dryer scenarios (such as HadCM3) lead to more carbon neutral conditions (Figure 18B).

Land use change alone has a positive effect on carbon storage, while climate change can counteract this effect (Figures 19, negative values denote fluxes into the terrestrial system, positive values denote fluxes out of the terrestrial system into the atmosphere). The differences between different storylines (A1f, A2, B1, B2) represent the opportunity of choice between different worlds. The effect of such choices on the European terrestrial carbon balance was examined using combined land use and climate change scenarios based on the four storylines. Generally it is found that reforestation, particularly on previously agriculturally used soils has a potential to sequester a notable amount of carbon, however, the uptake is never as strong as 10% of the EU's 1990's emission (Figure 20A, compare effect of climate change and land use change driven NBE, upper maps, with NBR driven by climate change only, lower maps). Climate change will interfere with this trend (as do other land use choices such as increasing urban area and regional shifts in agricultural areas). The variation over different climate model runs (A2 with four climate models) and the variation over four socio-economic storylines (A1f, A2, B1, B2 with climate model HadCM3) is similar (variation represented by standard deviation, Figure 20B). This indicates that a considerable amount of the variation in Europe's terrestrial carbon balance lies in the choices we make concerning our socio-economic future.

In our simulations climate change dominates the overall trend in European wide net carbon exchange. However, the EFISCEN model used in the forestry sector to simulate the growth of managed forests indicates that forest management may be at least as important a driver as climate change and land use in Europe (see section *Forestry*). Being a forest model, the EFISCEN cannot give results for the total terrestrial carbon balance of Europe, including crop- and grassland. The LPJ model gives an approximation of the total terrestrial carbon balance, however, the exact current and future total terrestrial European carbon balance is still unknown. The influence of human management and nutrition changes need further attention, as do the process of soil carbon mineralisation, plant product harvesting and the life time of the harvested products. The LPJ consortium is currently working to further improve the representation of forest and agricultural management in the LPJ model.

A number of papers have already been published and others are in preparation for peer-reviewed journals (see Annex 2).

Flux data benchmarking

Principal investigators: Pablo Morales, Pete Smith, Martin T. Sykes, Ben Smith, Colin Prentice, Harald Bugmann, Pierre Friedlingstein, Bärbel Zierl, Anabel Sánchez, Santi Sabaté, Eduard Pla, Carlos A. Gracia, Sönke Zaehle

The evaluation and comparison exercise of four process-based vegetation models (providing monthly output) that are part of the ATEAM project using a monthly dataset of carbon and water fluxes over fifteen EUROFLUX sites was completed.

A paper on the comparison is to be submitted shortly to *Global Change Biology* (see Annex 2).

Temperature dependency of soil respiration

Principal investigators: Jo House, Colin Prentice (with Wolfgang Knorr, Max Planck Institute for Biogeochemistry Jena and Beth Holland, NCAR, USA)

In an ongoing examination of the controversial issue regarding the effects of temperature on soil respiration, modelling studies were completed and a paper prepared in 2003. The paper has been revised and submitted to Nature as a letter (see Annex 2). We found that the controversial results could be accounted for providing a multiple-pool approach was used. Since this is the approach used by LPJ and ROTH-C, we concluded there was no need to alter the models used in the ATEAM Project.

6.2.2.4 Water

Principal investigators: Nigel Arnell and David Wilson

This part of the ATEAM project used a hydrological model to simulate the potential changes in streamflow and indicators of water resources across Europe following defined climate and land cover changes.

The project applied an established macro-scale hydrological model to simulate runoff across Europe at a resolution of 10'x10'. In general terms, the model (Arnell 1999; 2003) calculates the evolution of the components of the water balance at a daily time step. Model parameters are not calibrated from site data, but are determined from spatial data bases. A validation exercise showed that the model simulated reasonably well the magnitude and variation in runoff across Europe.

The model is run using the time series of monthly precipitation from 1961 to 1990 to simulate a sequence of 30 years of monthly streamflow in each grid cell. Different sequences of random numbers used to generate daily precipitation and temperature produce slightly different streamflow sequences, and in order to reduce the effect of this random variation each time series is simulated six times.

Although the model is implemented at a scale of 10x10', for most of the analyses runoff is aggregated to the 0.5°x0.5° scale. Döll and Lehner's (2002) drainage direction map is used to link the 0.5°x0.5° cells together and enable the accumulation of flows along the river network. The following hydrological and water resources indicators have been calculated under current and future conditions:

– runoff by grid cell

- runoff by major European basin
- water resources per capita by major European basin
- summer runoff volumes by grid cell
- annual runoff that is exceeded in nine years out of ten (“drought runoff”)
- maximum monthly runoff as indicator of change in flood regime (“flood runoff”)
- mean monthly regimes at a number of identified locations along major rivers

Ideally the calculations at the basin scale would use the major river basins defined for the implementation of the European Framework Water Directive, but unfortunately these have not yet all been precisely defined (European Commission, 2002). A total of 94 major river basins have therefore been identified, based on currently-proposed river basins and major topographic boundaries. Basin areas range from just over 10,000 km^2 to 373,000 km^2.

Changes in hydrological regime

Figure 21 shows the change in average annual runoff, at the 10x10’ grid scale, by 2021-2050 under the A2 emissions scenarios. Whilst there is some broad consistency in the pattern of change – reductions in runoff in southern Europe and increases in northern Europe – the magnitudes and precise geographic patterns vary between climate models. Reductions in 30-year mean runoff in parts of southern Europe can be as great as 30%; percentage increases in northern Europe are smaller. Separate model runs keeping land cover constant have shown that changes in climate have a much greater effect on changes in runoff than alterations to catchment land cover.

Figure 21 also shows change in “drought” runoff (the annual runoff exceeded in nine years out of ten) and “flood” runoff (the mean maximum monthly runoff). Note that neither have been routed, so represent drought and flood characteristics in small catchments, not characteristics along the major rivers in Europe. In general terms, the patterns of change are the same as for annual runoff, but there are some differences. Percentage reductions in drought runoff tend to be larger than percentage changes in annual runoff and, under HadCM3 at least, in some areas of northwestern Europe climate change may produce simultaneously more severe droughts and more extreme floods. Much of the large reduction in maximum flows in eastern Europe is due to the shift in timing of flows from spring to winter, as a greater proportion of precipitation falls as rain rather than snow.

Figure 22 summarises changes in mean monthly flow regimes at three locations along major European rivers – the Rhine, Rhone and Danube – under the HadCM3 scenario for 2021-2050. In each case there is a change in the timing of river flows, largely due to the reduction in the amount of snowfall and hence spring snowmelt, which will affect both navigation and run-of-river hydropower potential.

Implications for indicators of water resources

A key indicator of water resources pressures in a basin is the amount of water available per capita. Two key thresholds are values of 1700 m^3 $capita^{-1}$ $year^{-1}$ – below which there are likely to be water-related resources problems – and 1000 m^3 $capita^{-1}$ $year^{-1}$ – below which there is real water scarcity at times of the year. Figure 23 summarises water resources pressures across Europe in 2051 under the A2 world. The left-most panel shows the distribution of resources per capita (by major basin) with an A2 population in the absence of climate change. The central panels show the change in basin average annual runoff under the four climate models, and the right-most panels show the distribution of resources per capita with climate change.

River basins with the lowest available water resources per capita, in the absence of climate change, are mostly in highly-populated western-central Europe. Note that the indicator used does not take into account actual abstractions of water: abstractions per capita are higher in southern Europe due to irrigation. Climate change tends to increase the numbers of basins in southern Europe with water scarcity. The spatial pattern of change is very similar with the other emissions scenarios and future populations, except that with the lower population increases under the A1, B1 and B2 scenarios the lower Danube basin has greater water resources than 1700 m^3 $capita^{-1}$ $year^{-1}$ in the absence of climate change.

Table 8 summarises the total numbers of people (within the basins shown in Figure 23) living in watersheds with less than 1700 m^3 $capita^{-1}$ $year^{-1}$. The table shows that a large proportion of Europe's population live in such watersheds, and that beyond the 2020s climate change increases the numbers affected.

Table 8. Numbers of people (millions) living in watersheds with less than 1700 m^3 $capita^{-1}$ $year^{-1}$, by socio-economic storyline (A1f, A2, B1, B2), assuming no climate change and climate change calculated by four GCMs (HadCM3, CGCM2, CSIRO2, PCM) in the years 2025, 2055 and 2085. The change in number of people (millions) due to climate change is shown as well.

	millions						Change (millions)			
	total population	no climate change	HadCM3	CGCM2	CSIRO2	PCM	HadCM3	CGCM2	CSIRO2	PCM
2025										
A1f	633.0	357.5	356.2				-1.3			
A2	646.4	365.6	364.2	364.2	364.2	364.2	-1.4	-1.4	-1.4	-1.4
B1	633.0	357.5	360.8				3.2			
B2	609.4	342.0	346.3				4.3			
2055										
A1f	610.5	286.0	350.8				64.8			
A2	656.1	331.0	376.7	379.6	374.5	375.7	45.7	48.7	43.5	44.8
B1	610.5	286.0	352.9				67.0			
B2	565.9	250.7	287.7				36.9			
2085										
A1f	570.1	249.0	324.6				75.6			
A2	716.3	437.4	465.5	461.4	449.0	444.9	28.1	24.0	11.6	7.5
B1	570.1	249.0	298.8				49.8			
B2	557.2	246.4	297.0				50.6			

Two papers have been published in the journal *Global Environmental Change*, other articles are in preparation (see Annex 2).

6.2.2.5 Biodiversity and nature conservation

Principal investigators: Sandra Lavorel, Wilfried Thuiller, Miguel B. Araújo

We used the BIOMOD framework (Thuiller 2003) to predict the current distribution of more than 2000 species across Europe (1350 plants, 157 mammals, 108 herptiles (reptiles and amphibians) and 383 breeding birds) using five bioclimatic variables. Species distributions were projected across Europe under current and future climate change scenarios. For 2080, we derived future distributions of the 2000 species under seven climate change scenarios (A1-A2-B1-B2 HadCM3, A2 CSIRO2, A1-A2 CGCM2). In contrast to results from the other sectors the biodiversity estimates have a coarser spatial resolution of 50 x 50 km.

In order to reduce the tremendous uncertainty associated with selection of methods in niche-based modeling (Thuiller 2004, Thuiller et al. 2004), we used eight different models for each species and selected for each scenario the most consensual one (the one closest to the average across models). We then derived projections under two extreme cases of dispersal, namely zero and full instantaneous dispersal (Thuiller 2004). These approximations bracket the most pessimistic and optimistic estimates of future species range as a way to capture unknown actual dispersal rates.

Major results for 2080 show great sensitivity of biodiversity under all climate change scenarios (Figure 24). A1-HadCM3 (A1f emissions calculated with climate model HadCM3) represents the most threatening scenario for species diversity with some regions expected to lose more than 80% of current species richness. This scenario also produces the greatest variability across Europe while B1-HadCM3 appears to produce the lowest species loss and species turnover by pixel.

These projections were also averaged and mapped by biogeographical regions (using the environmental classification proposed by Metzger et al. 2004). Assuming no dispersal, the regions most at risk under A1-HadCM3 are Mediterranean mountains, the Lusitanian and Pannonian regions (mean percentage of species loss = 55%), while the regions in which the lowest extinction by pixel is expected are the Alpine north, Mediterranean south, boreal and Atlantic regions (Figure 25). The ranking of regional sensitivities was consistent across scenarios.

The detailed examination of the projections for plants in 2050 under the full dispersal hypothesis revealed that 93% of species were projected to have overlapping populations with current distributions, while 2% had totally non-overlapping future distributions and 5% lost all available habitat (Araùjo et al. 2004). These changes meant that, over a range of reserve selection methods, 6% to 11% of species modelled would be potentially lost from selected reserves in a 50-year period.

The modeling framework used here was developed to allow reserve area selection to optimize the protection goal of nature conservation areas under restricted resources and changing climate. A flexible management of nature reserve areas is necessary to maintain the conservation effect under changing conditions.

Numerous papers have been produced which are listed in Annex 2, including a contribution to *Nature*.

6.2.2.6 Mountains

Principal investigators: Harald Bugmann and Bäbel Zierl

Mountains and their ecosystems provide many goods and services to European societies, including freshwater supply, carbon storage, protection from natural hazards, and tourism related services such as maintaining a reliable snow cover for skiing. Some of these services have been dealt with in previous sections (carbon storage, water), this section provides an additional Alpine focus, based on a special approach that is suited for mountainous systems. The continued capacity of mountain regions to provide ecosystem services is threatened by the impact of environmental change. Therefore, the objective of our contribution to ATEAM was to perform high-resolution case studies in mountain catchments in order to assess the vulnerability of sectors that rely on mountain ecosystem services to global change.

We used five catchments representing different major climatic zones in the Alpine area: the Alptal, the Hirschbichl, the Dischma, the Saltina and the Verzasca catchment (Table 9). Plans to extend the approach to other mountain ranges of Europe had to be abandoned because of time constraints and limited data availability.

Table 9. Description of case study catchments from various climate zones in the alpine region. The category ‘rest’ in the column ‘land cover’ includes predominantly rocks, but also sealed areas such as cities, streets, or parking places.

case study catchment	region	area	precipi-tation	altitude	land cover (%)		
		(km^2)	(mm)	(m)	Forest	Grass	Rest
Alptal (CH)	western prealpine	46.75	2110	1150 (850 – 1860)	52	42	6
Hirschbichl (D)	eastern prealpine	44.61	1640	1460 (680 – 2560)	49	36	15
Dischma (CH)	high alpine	43.16	1310	2370 (1680 – 3110)	10	54	36
Saltina (CH)	inner dry alpine	77.02	1340	2010 (680 – 3400)	35	34	31
Verzasca-Lavertezzo (CH)	southern prealpine	44.13	2320	1680 (540 – 2500)	64	19	17

The simulation system RHESSys (http://typhoon.sdsu.edu/Research/Projects/RHESSYS, Tague and Band, 2004, Band et al., 1993) was used for simulating the fluxes of water, carbon and nitrogen through mountain catchments. First, the model was adapted to alpine conditions, particularly regarding maintenance respiration, phenology, snow accumulation and melting; second, it was validated against observations; and third, it was applied to project future development in the case studies. The model was spun up to a long-term equilibrium using temporally and spatially downscaled data (1900-1950, recycled) from the ATEAM climate scenarios and from local land use maps (sources: Arealstatistik, Bundesamt für Statistik, Switzerland; Nationalpark Berchtesgaden, Germany). RHESSys was then initialised with these spin-up results for the scenario simulations.

Seven different scenarios of climate and land use change (1950-2100, ATEAM, A1f HadCM3, A2 HadCM3, B1 HadCM3, B2 HadCM3, A2 CGCM2, A2 CSIRO2, A2 PCM) were downscaled to the case study areas and used to simulate daily stream flow, snow water equivalent and carbon cycling for the time period from 1950 to 2100. Finally, the simulated data were aggregated and evaluated to obtain indicators of mountain ecosystem services: annual and summer stream flow, and maximum monthly peak flow, carbon storage in the vegetation, reliability of the snow cover, and number of heat and rainy days. Furthermore, the results were interpreted with respect to natural hazards and tourism.

Assessments of the potential impacts of climate and land use change on fresh water supply, carbon storage, natural hazards (floods) and tourism were conducted for five Alpine catchments. It showed that one of the most sensitive processes in the Alpine region is the temporary storage of water during the winter season in form of snow and ice that (1) brings about a delay in stream flow, (2) controls the flood regime, and (3) constitutes an indispensable prerequisite for winter tourism.

Simulation results show that under a warming climate, the snow cover will diminish substantially. As a consequence, (1) summer discharge of Alpine catchments will significantly decrease, affecting the irrigation and hydropower sectors, (2) winter floods will become more frequent, influencing protection strategies, and (3) the snow line will rise, impacting winter tourism.

Finally, mountain regions and their ecosystems are potential carbon sinks, because highland agriculture and grazing land are being abandoned and become reforested by natural regeneration or tree planting and because forests at high elevations profit from the warming climate. However, the sink capacity is expected to decline after approximately the first quarter of the 21st century.

Fresh water supply in mountain catchments

At present, the typical Alpine stream flow pattern is characterized by a single-peak regime with maximum flow occurring between May and June. All scenarios produce a change in this regime. The annual pattern of discharge becomes flatter with rising temperature, i.e. summer discharge decreases and winter discharge increases (Figure 26).

Summer discharge in mountain catchments is most sensitive to a warming climate. It strongly depends on snow accumulation and snowmelt. During winter, water is stored as snow or ice at high elevations. In spring this water is released and strongly contributes to summer stream flow. Under a warming climate, this storage function of the snow cover is reduced. Furthermore, enhanced evapotranspiration in summer further reduces soil moisture content and consequently summer stream flow.

The simulations show a decrease of summer discharge between 5% and 50% over the next century (Figure 27). At the same time, monthly peak flows in summer decrease and shift to earlier dates by up to one month within the 21st century in most catchments and for most scenarios as a result of the diminished snow cover in winter. In contrast, none of the simulations that were performed revealed significant changes in annual stream flow.

Floods in the Alpine area

Currently, most of the major floods in the Alpine area occur in summer. Model results indicate that this summertime characteristic will shift towards or even into the winter half year as all scenarios produce a decrease in summer stream flow, an increase in winter stream flow and a shift of monthly peak flow to earlier dates (Figure 28). As a consequence, winter floods will become more frequent, and at lower lying Alpine catchments they might even become more common than summer floods under a warming climate. Regarding summer floods, the reduction of the winter snow cover will substantially reduce the frequency of floods caused by the snowmelt alone. However, it is difficult to achieve reliable estimates of daily peak flows under changed climate conditions, as the currently available state-of-the-art climate scenarios only give a very rough estimation of future daily precipitation.

Tourism and recreation in the mountains

Snow cover, an indispensable prerequisite for winter tourism, is highly sensitive to changes in temperature. Simulations indicate that the elevation of a reliable snow cover will rise between 200 m and 400 m, i.e. from about 1300 m a.s.l.[22] today to 1500-1700 m a.s.l. at the end of the 21st century (Figure 29). The predicted increase in winter precipitation can partly compensate for the temperature-related rise of the snow line, but it cannot prevent the upward shift. At present, about 85% of all Swiss ski areas still have sufficient snow. A 300 m rise of the snow line, however, would reduce this to about 63% (cf. Elsässer & Messerli, 2001). Sensitivity studies for the five catchments have shown that the elevation of reliable snow cover moves upward by approximately 150 m per degree Celsius of warming.

An analysis of the number of summer heat days revealed that particularly in the southern Alps heat days become more frequent, which likely reduces the attractiveness of this area for a range of outdoor activities such as hiking or biking. In the northern Alps, only a slight increase in the number of heat days was found. Regarding the number of rainy days, the analysis showed no significant change.

Carbon storage in mountain vegetation

Simulating the impact of climate and land use change on carbon storage in the vegetation, it became clear that land use change is the dominating process at the local scale (100 m to 1000 m). The alpine catchments under investigation show strong local signals in carbon emission or uptake depending on the land use scenarios (Figure 30), which predict changes in forest area by up to ±25%.

Compared to changes in land use, climatic shifts only marginally affect this ecosystem service at the local scale. However, climate becomes more relevant at the catchment scale. Figure 31 shows the development of vegetation carbon storage averaged over the catchment areas for the four ATEAM time slices. According to the model calculations, the biosphere currently acts as a sink. This sink slightly increases in the second time slice. This is mainly driven by the extension of the forested area (abandonment of alpine pastures) and by the temperature-related increase in carbon stock at high elevations. In the third and fourth time slice, however, this sink weakens or even becomes a source for some scenarios, as carbon stocks at low elevations decrease caused by amplified respiration. However, these results are subject to considerable uncertainties, as carbon cycling, particularly respiratory processes at high elevations is so far not fully understood, the model was not validated at high lying plots, and changes in plant functional type and tree migration to higher regions is not included in this simulations.

A number of papers to be submitted to peer-reviewed journals like *Water Resources Research* and *Ecosystems* are currently being prepared (see Annex 2).

6.2.3 Adaptation (WP1 and 5)

Adaptation is any adjustment in natural or human systems in response to actual or expected environmental change, which moderates harm or exploits beneficial opportunities (IPCC 2001). Adaptation can be autonomous and planned. Autonomous adaptation is “triggered by ecological changes in natural systems and by market or welfare changes in human systems, but does not constitute a conscious response to environmental change” (IPCC 2001). Autonomous adaptation changes sensitivity by changing a system’s state. In other words, it is part of the internal feedbacks in the human-environment system and its subsystems like ecosystems and markets, such as when forest tree species extent their bioclimatic range due to evolutionary adaptation, or the demand is slowed in a market after price increase resulting from supply shortages. However, ecosystem models are currently

[22] m a.s.l. = meters above sea level.

hardly able to represent such system state changes, i.e. they do not dynamically model adaptive feedbacks in a coupled way (Smith et al. 1998).

Adaptation also comprises planned adaptation. Planned adaptation can take place locally, as adaptive management decisions by individuals or small planning groups, such as planting a drought resistant crop type. Furthermore, planned adaptation can be implemented on a larger or macro-scale by communities and regional representatives, such as establishing flood plains to buffer seasonal river-runoff peaks. In this study, we distinguish such local scale and macro-scale adaptation, with the awareness that this separation is not always clear. Local scale adaptation is captured in our ecosystem models by taking into account local management e.g. in agriculture, forestry and carbon storage. Macro-scale adaptation enters our assessment in two ways. Broad overarching management choices based on the SRES storylines are incorporated in to the land use scenarios (Rounsevell et al., in prep) via the IMAGE model, which considers the impacts of climate change and CO_2 concentration on, for example, crop yields and markets. Secondly, the capacity of regions for macro-scale adaptation is considered by a generic adaptive capacity index. This index of adaptive capacity enters the vulnerability assessment directly, and is described in the next section.

6.2.3.1 Modelling adaptive capacity

Principal investigators: Richard Klein, Lilibeth Acosta-Michlik, Dagmar Schröter, Pytrik Reidsma, Marc Metzger, Rik Leemans, Mark Rounsevell, Miguel Araujo, Eva Kamphorst, Uta Fritsch

The vulnerability of people depends on *potential impacts* on the human-environment-system and on their ability to adapt to such potential impacts, i.e. their *adaptive capacity*. Since the ATEAM project is very much rooted in the ecosystem modelling community, we were unsure how to include human adaptive capacity. First ideas were to discuss thresholds of adaptive capacity with stakeholders. However, this did not yield results that could easily be combined with our quantitative maps of potential impacts. Therefore we decided to develop an index of adaptive capacity that would be quantitative and spatially explicit.

The concept of adaptive capacity was introduced in the IPCC Third Assessment Report (IPCC TAR, McCarthy et al. 2001). According to the IPCC TAR, factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital. Most adaptive capacity research to date has been conceptual in nature, asking questions such as “what is it?”, “what determines it?” and “how can it be measured?”. One paper has made an attempt at quantifying adaptive capacity based on observations of past hazard events (Yohe and Tol 2002). For the ATEAM vulnerability assessment framework, we were seeking present-day and future estimates of adaptive capacity that are quantitative, spatially explicit and based on, as well as consistent with, the scenarios produced by the IPCC in its Special Report on Emissions Scenarios (SRES, Nakicenovic and Swart, 2000). In addition, the adaptive capacity model and its results must be scientifically valid and comprehensible to stakeholders. The index of adaptive capacity we developed to meet these needs is an index of the macro-scale outer boundaries of the capacity of a region (i.e. provinces and counties) to cope with changes. The index does not include individual abilities to adapt.

Our approach to developing an index of adaptive capacity for use in ATEAM has been shaped by an extensive literature review on adaptive capacity and on vulnerability and sustainability indicators, as well as by discussions with project partners. The first step was to choose determinants of adaptive capacity and to select indicators for these determinants. To obtain scenarios of adaptive capacity we also needed future projections of the data. However, only for population and gross domestic product (GDP) such data were available (downscaled SRES projections). Therefore time series data (1960-2000) for all indicators were collected on a regional scale (NUTS2 level[23]). Next, the functional relationships between

[23] NUTS2 - Nomenclature des Units Territoriales Statistiques 2: regions or provinces within a country. There are around 500 NUTS2 units, as apposed to only 17 EU countries.

the indicators and population and GDP data were developed. Indicator scenarios were then extrapolated using the historical functional relationships between the respective indicator and population and GDP. Finally, we developed a conceptual framework to aggregate indicators to a generic index of adaptive capacity in three steps using a fuzzy logic approach. For future scenarios of the index of adaptive capacity, the projected indicator data were aggregated per scenario and time slice.

To guide our choice of determinants of adaptive capacity, we used a set of questions that would provide insight into different aspects of adaptive capacity (Table 10). We then looked at the availability of indicators of these determinants (Figure 32). Neither the list of determinants or the list of indicators are exhaustive but rather a compromise between rational justification and availability of data.

Table 10. Guiding questions to the conceptual framework of adaptive capacity and related determinants. The list of determinants is restricted by the availability of indicators. The List of indicators can be found in Figure 32.

Guiding question	Related components of adaptive capacity	Related determinants of adaptive capacity
Is awareness building encouraged in society?	Awareness	Equality
Is society aware of the issue and does it perceive it as a problem?	Awareness	Knowledge
Is society equipped to address the problem?	Ability	Technology, Infrastructure
Is society constrained to take action?	Action	Flexibility, Economic power

The aggregation is performed acknowledging that adaptive capacity is not a binary concept. Literature and expert knowledge helps to classify a particular indicator value as low, medium or high, which then defines membership functions for each indicator. Inference rules are then applied for stepwise aggregation of indicators (*e.g.*, if literacy rate is high and enrolment ratio is medium, then knowledge is high). Fuzzy set theory then produces a value between 0 and 1 for the adaptive capacity index. The aggregation is performed in three steps: from the list of indicators to the six determinants, which are then aggregated into the three components, which are then aggregated into an adaptive capacity index (Figure 32).

Using this methodology, maps of the generic adaptive capacity index for the four SRES scenarios and four time slices for each of the scenarios were produced (Figure 33). The top row shows an initial step of ‘calibration’, i.e. comparing the adaptive capacity index based on observed data from 1995 with the maps of extrapolated data for the baseline year 2000. Both maps show about the same patterns of adaptive capacity, with improvements in adaptive capacity in most areas in the year 2000.

Areas in the Iberian Peninsula and Greece tend to have low macro-scale adaptive capacity relative to Northern European regions. Comparing the different SRES scenarios over time, macro-scale adaptive capacity generally increases over time. In areas where it slightly decreases again towards 2080, e.g. France in A1 2020 compared to 2080, this leads to a more homogeneous pattern within Europe.

The maps of macroscale adaptive capacity index allow comparison between regions and scenarios. On first sight the spatial and temporal patterns of the preliminary maps of adaptive capacity make sense. Nevertheless, further analysis of the underlying data is needed. The sensitivity of the index to changes in these data needs to be further explored. One next step is to carry out a sensitivity analysis of the membership functions in the fuzzy model and of the indicators.

The preliminary results shown here seem reasonable, but are work in progress. Whilst this approach has produced the first spatially explicit projections of future adaptive capacity, the preliminary maps can be improved in a number of ways, including increasing the number of independent variables for the indicator scenario development or using more variables for the regression analysis (multivariate analysis), and developing adaptive capacity indices that are specific for particular sectors or climatic events. All usual and well-documented problems with using indices apply to this way of assessing adaptive capacity as well. It would be interesting to explore the possibility of 'validation' of this adaptive capacity approach using historical data of past hazards in regional comparison.

Our impression from the last stakeholder workshop, where we discussed this index is that stakeholders show little interest and trust in this indicator. As individuals they are concerned with their individual adaptive capacity, which is not captured by the index. They were however willing to see this as a first attempt to capture the regional context in which they make decisions. Not surprisingly though, the indicators used as components of the index were questioned. In the age of mobile telecommunication, 'Number of telephone lines', as used in this approach, will not adequately indicate a region's communication infrastructure. The choice of indicators and the spatial resolution of the adaptive capacity model are constrained by the availability of data. Even though it is quite clear that adaptive capacity will be sector specific and depend on the nature of the exposure, we had insufficient information, time and budget to assess adaptive capacity per sector or per global change event.

When asked the crucial question, whether using a generic indicator of adaptive capacity in vulnerability assessments can be better than no indicator at all, many colleagues clearly agreed to use such generic indicators. Nevertheless, we are very aware of the limitations of such an approach. We therefore wish to state clearly that our adaptive capacity index is designed for use within a European vulnerability assessment which is carried out for the fifteen EU countries plus Norway and Switzerland. The index does not include individual abilities to adapt, but it can give a context in which individuals adapt. The macroscale adaptive capacity index indicates part of the adaptive capacity of a region (i.e. provinces and counties) to cope with changes. For example, while the index cannot indicate whether individuals will exhibit precautious behaviour when faced with flood risk, it can indicate a regions capacity to change the river bed in order to decrease the likelihood of flooding.

The approach has been presented at various conferences and a publication to be submitted to *Global Environmental Change* is currently being prepared (see Annex 2).

6.2.4 Stakeholder dialogue (WP1 and 5)

A dialogue between stakeholders and scientists was initiated at the beginning of the project and has been continued, intensified, and evaluated. The general objective of this dialogue was to facilitate a more appropriate assessment of vulnerability, i.e. to produce results that would adequately inform the decision-making of stakeholders. In particular the aims of the stakeholder dialogue were to (1) identify indicators of changes in ecosystem services; (2) settle useful scales and units at which these indicators should be measured or modelled; (3) discuss thresholds for these indicators that represent limits outside which the adaptive capacity of the sectors is exceeded; and (4) present and discuss results as well as the format they are presented in (clarity of maps, graphs, etc). Stakeholder dialogue activities have focussed on confirming stakeholders' interest on ATEAM's scientific goals, enhancing the stakeholder network, following a coherent dialogue strategy, and, most important, obtaining critical insights, requests and comments from stakeholders on our approach and results. Practical steps in this were the preparation, running, evaluation and reporting of a number of workshops, and the development of an evaluation and dissemination strategy.

In the course of the communication between ATEAM and the stakeholders we have structured the assessment into six sectors labelled as follows: (1) agriculture; (2) forestry; (3) carbon storage & energy; (4) water; (5) biodiversity & nature conservation; and (6) mountains (especially tourism & recreation). It was recognised that the sectors, as well as the ecosystem services they use, are highly interdependent. They are also only an incomplete selection of possible sectors to be studied in a vulnerability assessment, although they are highly suitable to demonstrate the approach and to yield first-order results.

6.2.4.1 The stakeholders

The identification of possible stakeholders took place by widespread inquiries via internet search, e-mail and telephone and a survey among ATEAM partners and colleagues. A vast database of potentially interested parties was created. To date 203 stakeholders have been identified, 152 were approached and invited to our activities and 58[24] were involved in at least one activity. The full ATEAM stakeholder database is located in Annex 4. Initially to facilitate the selection process a matrix was designed with relevant sectors vs. geographical focuses/scales and organisation type. The aim was to systematically produce a sample/database of stakeholders to contact and hopefully involve during the course of the project.

In preparation of the stakeholder involvement the ATEAM approach was structured into sectors and preliminary vulnerability indicators were identified as basis for the discussion between stakeholders and scientists. ATEAM targeted in particular sector and corporation representatives and consultants, policy advisers, environmental resource/park managers, farmers/foresters, NGOs, journalists and academics. Table 11 below illustrates the type of stakeholder organisations ATEAM involved.

[24] This number does not takes into consideration: 1) stakeholders involved during other dissemination and outreach activities carried out within the ATEAM project and reported upon annually, and 2) the stakeholder networks developed within other projects or institutes mentioned in the report and within the activities of which ATEAMers participated.

Table 11 Targeted sectors[25] vs. stakeholder organisational types[26] . Numbers of stakeholders who participated in one or more ATEAM dialogue activities are shown, the number in brackets shows the number of stakeholders who were identified and/or approached (but did not participate).

	Sectoral consultancy	Sectoral rep.	Private business	Public body/ academic	Public body/ advise to policy	Public body/ resource management	NGO	Independent umbrella organisation	TOTAL
Agriculture	1 (2)	2 (10)	0 (2)	2 (2)	0 (0)	0 (1)	0 (0)	0 (1)	**5 (18)**
Biodiversity	1 (1)	0 (0)	0 (0)	4 (7)	2 (11)	3 (8)	1 (6)	0 (0)	**11 (33)**
Carbon storage	1 (5)	0 (0)	0 (5)	2 (7)	4 (17)	0 (0)	2 (3)	1 (5)	**10 (42)**
Forestry	2 (3)	7 (19)	0 (6)	3 (5)	4 (7)	2 (2)	1 (2)	0 (1)	**19**
Insurance	0 (0)	0 (0)	0 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (4)**
Media	0 (0)	0 (0)	2 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**2 (5)**
Mountain environments	0 (0)	0 (1)	1 (3)	0 (2)	1 (1)	1 (1)	0 (0)	2 (10)	**5 (18)**
Tourism	2 (13)	0 (1)	0 (1)	0 (2)	0 (0)	0 (0)	0 (2)	0 (0)	**2 (19)**
Water	1 (5)	0 (0)	2 (6)	1 (2)	0 (5)	0 (0)	0 (0)	0 (1)	**4 (19)**
TOTAL	**8 (29)**	**9 (31)**	**5 (32)**	**12 (27)**	**11 (41)**	**6 (12)**	**4 (13)**	**3 (18)**	**58 (204)**
	Private	**22 (92)**		**Public**	**29 (80)**		**Independent**	**7 (31)**	

For clearly economic sectors such as agriculture, forestry, tourism, and water we targeted in particular the private sector (i.e. sectoral representatives, consultants and private businesses). We assumed that private decision-making and management of ecosystem services is of paramount importance here. In contrast to this, the preferred stakeholders for biodiversity, carbon storage and mountain environments were from the public (academic/advisory/management public bodies) or independent sector (NGO, umbrella organisations). Indeed the associated ecosystem services are often neither directly valued economically nor traded and relate to national and/or European policy making issues (e.g. climate protection, ecological directives).

[25] Sectors targeted for the stakeholder dialogue do not correspond exactly to the ATEAM sectors *per se* which are Agriculture, Forestry, Carbon Storage, Water, Biodiversity and Nature conservation, and Mountains.

[26] The following organisational types were involved:

Sectoral consultancy: these can be commercial (e.g. DHI Water & Environment) or non-profit consultancies (e.g.: Associazione Cultura Turismo Ambiente - ACTA).
Sectoral representative: include farmers' union, cereal growers, land and forest owners, paper-agro industries, insurances etc.
Private business: from individual farmers to multinational corporations (e.g. IKEA, TETRAPACK, Gerling Reinsurance).
Public organization whose main focus is to advise policy: these can be statutory or not, directly be involved in policy/decision-making (e.g. Ministries of Environment, European Commission) or in advisory position (e.g. European Environmental Agency).
Public organization whose main focus is academic: research institutes who were not directly involved in ATEAM.
Public organization whose main focus is environmental resource management: e.g. forest, water and or natural park management.
Non governmental organization: from globally known organizations such as WWF, Greenpeace, to nationally important ones, such as Robinwood (Germany), to the Liga para a Protecção da Natureza (Portugal).
Independent umbrella organisation: these can be non-profit organisation focusing on awareness raising (e.g. Climate Network Europe, Commission internationale pour la protection des Alpes – CIPRA) to organisation fostering trade (e.g. Organisation for Economic Co-operation and Development – OECD, Association of British Travel Agents). See Annex 4 for the full list.

As presented in Table 12, most targeted and represented organisations have a European to Global focus of activity. We considered groups of countries, which had some geographical unity across Europe, to also address regional and national perspectives. The Mediterranean and Alpine regions are best represented, and Scandinavia less so. Although the ATEAM window covers a large part of central and eastern Europe, the formal focus was on the EU-15 + Norway and Switzerland. Potential stakeholders in central and in eastern Europe were thus not extensively searched and only one organisation was identified and contacted. Finally, large countries like France, Germany and the UK were given special attention. This bias somewhat reflects existing networks within the consortium, which were more easily activated than completely new stakeholder contacts.

The full list of ATEAM stakeholders is given in Annex 3.

Table 12. Main geographical focus of ATEAM stakeholders' activity[27].

	Full database	Participants
Global	10	0
Europe/Global	40	8
Europe	40	9
Alpine	22	8
Central Europe	1	0
Mediterranean	22	7
Scandinavia	12	2
France	7	3
Germany	30	16
UK	20	5
TOTAL	**204**	**58**

A number of participants' characteristics are critical in fostering a successful dialogue process. We believe that an open and critical mind, and curiosity in all participants are key components for an enriching and challenging dialogue from which not only scientists but also stakeholders can profit. For the purposes of this specific dialogue, ATEAM often contacted organisations and/or individuals, which explicitly showed some interest in environmental issues and/or (sustainable) management of natural resources. When however specific commercial organisations (e.g. IKEA, TETRAPACK) were approached, interlocutors often declined ATEAM's invitation. This may be both that we failed to show representatives of these firms how we could provide relevant information to their activity, as well as perhaps a restricted interest in global change impacts modelling. This introduces a "green" bias in our stakeholder community. However, we targeted stakeholder organisations that showed a critical competence in (inter)sectoral issues, as well as a substantial understanding of scientific approaches and interests.

Some of these above selection criteria can be used in web searches (e.g. by targeting the environmental department of a firm), others can only be applied through personal contact and experience of cooperation (e.g. qualities like a 'critical and open mind' and 'curiosity'). Lastly, known and

[27] *Global:* International organisations (e.g. WWF)

Europe/Global: European organisations which have international outreach/interests (e.g. IKEA, European Environmental Agency)

Europe: Supranational organisations the activity of which is primarily of European relevance (e.g. CIPRA)

Alpine region: including Austria, France, Germany, Italy, Liechtenstein, Slovenia, Switzerland

Mediterranean region: including Albania, Croatia, France, Greece, Italy, Malta, Monaco, Portugal, Slovenia, Spain,

Scandinavia region: including Finland, Norway, Sweden

France: organisations which have a full French coverage (i.e. regional/local organisations located in the Mediterranean zone are here placed under the Mediterranean region above.

respected interlocutors often have a very busy schedule, which makes it difficult to secure their presence. Typically they are in a hierarchical situation and delegate the attendance to a colleague. This sometimes helps meeting the people who “do the work” rather than those who represent and manage. In this way welcoming someone who was not initially approached can uncover valuable new contacts. However, in that case the organisers have little control over who should participate and meet some difficulty in assessing their potential needs and input to the dialogue.

6.2.4.2 Materials produced for the stakeholder dialogue

First of all material was produced to support and guide the ATEAM scientists in the stakeholder dialogue. Each workshop event was carefully prepared and ATEAMers were provided with all necessary background material for the event, such as scope, objectives, format, agenda, list of participants etc. ATEAMers supported each other in entering this new endeavour and keeping up a spirit of common ATEAM identity, curiosity and tolerance throughout the dialogue. Furthermore, we provided short biographies and profiles of the stakeholders they met, guidelines on how to present their approaches and results, and templates for common formats of flyers, posters and presentations. We also produced a set of guidelines and tips to support ATEAMers in moderating the plenary and break-out group discussions.

We set up a number of web pages[28] that are especially targeted at stakeholders to introduce the project, exchange material and provide a list of stakeholders already involved. We introduced ourselves to stakeholders via personal letters as well as phone calls. Further personal letters were send to maintain the stakeholder contacts. During stakeholder interactions at the workshops we provided a range of informative material, a full list of which can be found in Annex 2 section *Material targeted especially at stakeholders.* Such material consisted of introductory flyers in English, French, Spanish, and German, flyers and posters on the ATEAM vulnerability concept, flyers and posters on the land use scenarios, flyers and posters summarising the methods and results per sector, and targeted summaries of workshop reports. At the workshops ATEAMers gave presentations following a common format and striving for a common language and nomenclature. This was supported by a project internal glossary (Metzger, M. and Schröter D. 2003. The ATEAM Glossary. 5 pp., see Annex 2). The presentations were introductory on general concepts and scenarios, as well as sector specific, on ecosystem modelling approaches and results. Additionally, stakeholder questionnaires were produced and distributed to evaluate the dialogue process and outcome (see section *Dialogue evaluation* below).

6.2.4.3 Activities with stakeholders

The events include general stakeholder meetings and sectoral workshops. Their aims and outcomes are summarised below.

Detailed reports of all events briefly described here were produced (see Annex 2).

Three general stakeholder meetings

The 1st Stakeholder Workshop, October 2001, L'Isle-sur-la-Sorgue, France

A group of ca. 120 potential stakeholders were reviewed and a small group of 16 of these were selected and approached via personal letter. In this first contact the ATEAM approach was described, explaining how the stakeholders could profit from a collaboration with the project. A flyer was developed and sent along for illustration. In preparation of the first stakeholder workshops the selected group was then contacted and interviewed by phone to ensure their participation and to sample their particular interest in ATEAM.

The ATEAM then realised its first stakeholder workshop “Initiating the ATEAM Dialogue: 1st ATEAM Stakeholder Workshop” Isle-sur-la-Sorgue, France, 22nd - 24th Oct. 2001 with a group of 9 stakeholders

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[28] These web pages can be reached through a link on the main ATEAM project web page or directly through: www.pik-potsdam.de/ateam/stakeholderweb/ateam_stakeholderstart.html

from different sectors and 18 ATEAM researchers and one observer. The workshop consisted of two and a half days of presentation, discussion and reviewing. It was embraced by a half-day pre- and a one day post-meeting without stakeholder participation. The pre-meeting served as preparation for the first stakeholder contact by reviewing the common strategy and dealing with last moment questions. The post-meeting was used to review the process, agree on a future strategy and to discuss general ATEAM issues.

After a general introduction to the ATEAM approach the results of preliminary analyses on ecosystem services for the different sectors (e.g. carbon storage, crop yield, wood production, biodiversity) were presented to illustrate possible outcomes of the project. Insights in the capabilities and limitations of ATEAM's models, data and scenarios were given in short presentations by ATEAM researchers per sector. Initial assessments of the vulnerability of certain ecosystem services to global change were shown. The following plenary discussions and break-out sessions then aimed to identify the specific needs of the stakeholders. The ATEAM enquired about the stakeholders' current use of environmental-change information and the format and scale of indicators that are frequently used in their sector.

This first stakeholder workshop initiated the dialogue process by mutual introduction and confidence building. Synergies have been created and enthusiasm over the dialogue has been built amongst partners and stakeholder alike. All nine stakeholders who participated declared that they were willing to co-operate with ATEAM over the longer term, and most of them did. The result of this first meeting was a preliminary list of indicators for ecosystem services that are relevant to the stakeholders. The list was characterised as preliminary, due to the small size of this first group of stakeholders. In the course of the stakeholder process the group was be enlarged and the list was be updated and expanded.

The stakeholder dialogue revealed the importance of several indicators that had not been pre-selected by us, such as bio-fuel production potential for stakeholders from the agricultural and forestry sector alike. Furthermore the suitability of crop and wood species and the necessity of management changes to adapt to global change were in the centre of attention for a successful interaction between the ATEAM scientists and stakeholders.

Conclusions from this first workshop on the dialogue process were that ATEAM should aim to include less academics and more environment resource managers and decision makers. Finally, we realised the importance of an active moderator to facilitate communication between stakeholders and scientists.

The 2nd Stakeholder Workshop, September 2002, Potsdam, Germany

The workshop was attended by 22 stakeholders from a larger contact database, 18 ATEAMers and one observer. Specific aims of this workshop were to present and discuss the ATEAM land use scenarios, ecosystem modelling methods and indicators, as well as sectoral adaptive capacity to global change. As before, ATEAMers had an internal meeting prior to the event to finalise preparation and harmonise the communication strategy.

Participants evaluated and discussed the ATEAM land-use scenarios and the vulnerability mapping methodology of the project, as well as the usefulness of preliminary model indicators. The overall response of stakeholders was a positive, stimulating and encouraging one. Specific stakeholder concerns were isolated and when possible were addressed within the project. Participating ATEAMers emphasised how collaboration and discussion with stakeholder had been beneficial and interesting. Wider discussions on sectoral and European vulnerability to global change and possible adaptation took place, as well as the identification of the most pressing research issues in ecological modelling and vulnerability assessment.

These issues were named as follows:

- the development of appropriate linkages of state-of-the-art land use scenarios and ecological modelling to management schemes, legal frameworks, cost-effectiveness, rural development and rural uses;

- the consideration of the interactions between land use, climate and policy; and,
- the need to bridge the gap between the current modelling scales and the scales relevant to policy and decision-makers.

The 3rd and final Stakeholder Workshop, May 2004, Potsdam, Germany

The final workshop was attended by 13 Stakeholders, 12 ATEAMers and 3 observers. In contrast to all other events, this time only accommodation and meals, but not the travelling costs were paid for stakeholders, due to budget constraints. We consider it a very positive signal that 13 stakeholders paid their own travel to participate in this final event. As before, ATEAMers had an internal meeting prior to the event to finalise preparation and harmonise the communication strategy.

The aim of the final workshop was to present and discuss near final results on potential impacts of global change on ecosystem services and sectors, sectoral adaptive capacity and resulting vulnerability. Furthermore, the ATEAM digital atlas of these results, the so-called mapping tool was presented and discussed.

In view of the potential impacts of global change on ecosystem services as calculated by ATEAM, sectoral adaptation was considered and debated. The ATEAM mapping tool was demonstrated and stakeholders commented on how this could be improved. Stakeholders usually praised the ATEAM goal, approach and preliminary results. The information on potential impacts per ecosystem service *per se* was judged more useful however than an aggregated indicator of vulnerability (including a macro-scale indicator on adaptive capacity). This suggests that vulnerability as a concept and its quantification may be of more scientific than social relevance. It could indicate that stakeholders are very well aware of the adaptive capacity of their sector and need primarily to understand the risk their activities face in the context of global change.

The need to include explicitly policy alternatives and their potential effect on ecosystem services, and to explore ways to attach probabilities to specific scenarios was highlighted. More transparent documentation was asked so as to understand adequately how the results were obtained and thus better judge their meaningfulness. This is especially important since the ATEAM mapping tool will potentially store 2500 maps. The mapping tool in itself was judged interesting and innovative, although stakeholders did not think they could use it in their daily decision-making and/or management work. Efforts to synthesise the information gained by the maps would be valuable and would increase the dissemination and use of the ATEAM results.

Sectoral meetings

Agriculture and biomass energy, February 2002, Paris, France

Participants: 3 stakeholders from agricultural and agronomical research institutes, 2 ATEAMers.

Aim: to discuss the ATEAM vulnerability assessment framework, scenarios and possible model outputs specific for agriculture, biomass energy and carbon storage.

A small bioenergy stakeholder workshop was held in January 2002 in France as a direct follow-up of the first annual stakeholder workshop, where the need for a smaller meeting became apparent and the event was planned. It focused on issues relating to agriculture, biomass energy and carbon storage. Three stakeholders from agricultural and agronomical research institutes were introduced to the ATEAM vulnerability assessment framework, scenarios and possible model outputs for their sector. The bioenergy workshop provided useful insight in to some of the areas of interest of stakeholders, and some ideas of how to proceed with inclusion of bioenergy within ATEAM modelling and analysis. Most of the bioenergy modelling was planned to be carried out as part of the agricultural sector as this was where ideas, methodologies and resources were most well suited.

Mountain ecosystems and their services, November 2002, Kappel, Switzerland

Participants: 6 Stakeholders whose activities were concerned with Alpine ecosystem services (e.g.

hydropower, tourism, nature conservation, carbon storage and forestry) and 5 ATEAMers.

Aim: to evaluate and discuss the first results of the mountain and biodiversity modelling groups.

First results from the ATEAM Mountain and Biodiversity modelling groups were presented, evaluated and discussed. Stakeholders emphasised that in particular, tourism is a sector that relies on an integrated protection of all ecosystem services. Furthermore the vulnerability of mountain sectors that depend on water quantity and quality, carbon storage and protection from natural hazards were discussed. All participants concluded that this had been a very fruitful meeting.

Forestry and forest management, joint activity of SilviStrat & ATEAM, November 2002, Finkenkrug, Germany

Participants: 12 forestry stakeholders from the state of Brandenburg (public and private forest owners, representatives of the timber industry and nature conservation groups) and 6 scientists from the SilviStrat and the ATEAM project

Aim: to discuss global change impacts on forest products, carbon sequestration, tree species richness, management practices, and the recreational value of forested areas.

Forest management changes during the last ten years led to a shift from coniferous monocultures to larger areas of mixed broad-leaved forest in the area. This development seemed to be supported by the forest industry, the forest owners and the nature conservation groups alike. With regard to likely consequences of climate change, stakeholders were especially interested in impacts on wood quality, tree species suitability and in the frequency of storm events and insect calamities. The interest in carbon sequestration strongly depended on EU policies and potential subsidies for this. A stakeholder from the timber processing industry stated that the adaptive capacity of this industry to changes in wood quality is very high, due to rapid technological development. All participants concluded that they have gained useful insights from the meeting.

ATEAM participation/representation at other stakeholder meetings

Confidence Building Measures by the EU on International Climate Change, German Foreign Ministry, May 2003, Berlin, Germany

The ATEAM vulnerability concept was applied to two contrasting cases (Saudi Arabia and Zimbabwe) in an invited key-note presentation given at the 3rd Meeting of Environmental Policy Departments of EU-Member States' Foreign Ministries *Confidence Building Measures by the EU on International Climate Change*. German Foreign Ministry, May 15-16, 2003, Berlin, Germany by Dagmar Schröter. The ATEAM vulnerability concept was thus communicated and discussed with a group of ca. 50 European diplomats to countries throughout the world, aiming to develop a common strategy in supporting climate protection policy through diplomatic action.

Second Climate Protection Workshop, May 2003, Wiesbaden, Germany

Representatives from all German federal states attended the conference *Second Climate Protection Workshop* organised by regional office for geology and the environment in Hessia in May 2003 in Wiesbaden, Germany. Wolfgang Cramer was invited to speak to this group of policy makers about *Consequences of climate change for the Federal States*. The ATEAM vulnerability concept and first results were presented and discussed at this large stakeholder event.

The biofuels directive: potential for climate protection, September 2003, Norwich, UK

The European Climate Forum organised a stakeholder conference at the Tyndall Centre, UK, entitled *The biofuels directive: potential for climate protection.* Jo House from our biogeochemistry modelling group was invited to speak at this event. She gave a presentation about *Land Use Scenarios for Europe: Biofuel Potential and Climate Change* (Sept. 2003, see list of presentations in Annex of Annual ATEAM Report 2003). ATEAM received vital feedback at the event which was summarised in a report to the consortium (see list of non-refereed media in Annex of Annual ATEAM Report 2003)

European greenhouse gas budgets of the biosphere, December 2003, Milano, Italy

Another stakeholder event at which ATEAM results were presented was organised by Claus Brüning as an EU carbon side event at COP9[29], *European greenhouse gas budgets of the biosphere*, December 10, 2003. Pete Smith and Wolfgang Cramer were invited and gave presentations on *European agriculture and carbon: the big unknown* (Smith), followed by *Ecosystem vulnerability and climate change* (Cramer). The event was chaired by Anver Ghazi (European Commission). Three other talks were given: *CarboEurope concerted action* (Riccardo Valentini), *The terrestrial carbon budget of European countries* (Ivan Janssens), and *Local measurements framed on the Kyoto Protocol* (Günther Seufert). Judging from feedback from participating stakeholders the event was successful in conveying the state of science with respect to carbon storage to COP9 delegates. ATEAMers took the opportunity to stress the importance of multiple scenarios of the European carbon balance.

Sustainable Forest Management Indicators: Application and Research, December 2003, Barcelona, Spain

Participants: 200 stakeholders from the forestry sector (including technicians, administrations, forest owners…) met during the workshop on *Sustainable Forest Management Indicators: Application and Research* (organised by CREAF - Centre de Recerca Ecològica i Aplicacions Forestals). Representatives of the ATEAM forestry-modelling group presented its work.

Aim: to present and discuss CREAF and ATEAM research and preliminary results.

Due to the large and diverse audience of participants, this event was a remarkable opportunity to present and make accessible to local stakeholders CREAF's findings developed within ATEAM. It contributed significantly to raise interest on the overall ATEAM project and to communicate its research.

Meeting of Swedish Bioenergy Association with Swedish Parliament, May 2004, Stockholm, Sweden

During the 3rd general stakeholder meeting Mr Nyström (Swedish Bioenergy Association)[30] was particularly interested in the ATEAM preliminary biomass energy case study results. In response to his own request ATEAM provided some material for meeting organised by the Swedish Bioenergy Association, which involved members of the Swedish Parliament. This was a good opportunity for ATEAM to be introduced and get more visibility among national scale policy makers.

Vulnerability Workshop at the 20th sessions of the subsidiary bodies UNFCCC, June 2004, Bonn, Germany

At the Twentieth sessions of the subsidiary bodies (SB 20), United Nations Framework Convention on Climate Change (UNFCCC), Dagmar Schröter was invited to present and represent the ATEAM vulnerability concept and results during the first session of the *Workshop on Scientific, Technical and Socio-Economic Aspects of Impacts of, Vulnerability and Adaptation to Climate Change*[31], June 16-25, Hotel Maritim, Bonn, Germany. The workshop explored three themes in three subsequent sessions. i.e. *Vulnerability & Risks*, *Sustainable Development*, and *Solutions & Opportunities*. The first session focussed on assessment and perception of risks at different scales and constituencies. During this session five panel members gave key note speeches on vulnerability and adaptive capacity: Zbigniew Kundzewicz, Polish Academy of Sciences ("Vulnerability, risk and adaptation to climate change"), Roger Jones, CSIRO Atmospheric Research Australia ("Using risk assessment to inform adaptation"), Mahendra Shah, IIASA ("Impact of climate change on agriculture - towards an integrated global assessment of potential economic and social costs"), Xuedu Lu, Ministry of Science and Technology,

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[29] COP9 – Ninth Session of the Conference of the Parties to the United Nation Framework Convention on Climate Change (UNFCCC), December 2003 in Milan, Italy.

[30] Swedish Bionergy Association - See: http://www.svebio.se/engindex.htm

[31] http://unfccc.int/sessions/workshop/180604/present.html

China (“The methods for impact study on climate change in China”) and Dagmar Schröter, Potsdam Institute for Climate Impact Research (“Global change vulnerability - assessing the European human-environment system”). Subsequently, the panel members discussed vulnerability and adaptation issues with the attending delegates, NGO representatives and scientists. This first session was attended by ca. 300 delegates from the UN Parties.

This workshop was held in response to a decision by the Parties to initiate new work under the Convention on "Scientific, technical and socio-economic aspects of impacts of, vulnerability and adaptation to climate change" after the Subsidiary Body for Scientific and Technological Advice (SBSTA) has completed consideration of the IPCC Third Assessment Report[32]. The workshop was somewhat unique in that it was the first time that an UNFCCC workshop was held *during* an official negotiating session. This timing was specifically requested by Parties to provide for a better exchange of information and experiences between experts/practitioners and *all* delegates attending the session. The ATEAM vulnerability assessment has therefore provided direct input to the discussions among stakeholders on a policy negotiation level at the UNFCCC.

Joint AVEC-EEA-MA workshop on the Future of Ecosystems in Europe, June 2004, Copenhagen, Denmark

Five ATEAMers participated in the *Workshop on Global Change and the Future of Ecosystems in Europe,* jointly organized by AVEC[33], The European Environment Agency (EEA)[34] and The Millennium Ecosystem Assessment (MA)[35], on June 10-11, 2004, in the European Environment Agency, Copenhagen, Denmark.

This workshop brought together scientists with policy advisors from the European Commission and from nine national governments. In opening the conference, EEA Executive Director Jacqueline McGlade emphasised that "managing European landscapes in the context of sustainable development requires sound up-to-date scientific information as well as a long-term vision for possible future development paths in all sectors involved in environmental decision making."

Scientists presented the assessment process and preliminary findings of the Millennium Assessment (MA), ATEAM and current EEA assessment and communication efforts to a large group of European scientists and policy makers. Wolfgang Cramer (project leader of AVEC and ATEAM) and Rik Leemans (leading ATEAM partner and MA co-chair, AVEC summer school tutor) co-organised the workshop, chaired sessions and led panel discussions. Dagmar Schröter (scientific coordinator ATEAM, AVEC summer school head of the tutors) and Marc J. Metzger (ATEAM partner, AVEC summer school tutor) gave an invited presentation of ATEAM’s vulnerability assessment methodology and results on potential global change impacts and vulnerability. Finally the digital atlas, or ‘mapping tool’ of ATEAM vulnerability maps was introduced and presented. Anne C. de la Vega-Leinert (coordinator of the ATEAM stakeholder dialogue, AVEC summer school tutor) participated in the discussions with a special focus on scientist-stakeholder communication.

The results, similarities and inconsistencies between different assessment methodologies were discussed. European representatives indicated which findings were most relevant for European policy over the short and longer term. Workshop participants agreed that scientists from social and natural disciplines, owners and users of the land and policy makers need to work together more closely to minimise the risk to biodiversity, agricultural and forest yield, water resources and other values. ATEAM’s achievements were recognized as fundamentally paving the way towards this closer

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[32] The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report 2001, www.grida.no/climate/ipcc_tar/

[33] EU concerted action: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC), www.pik-potsdam.de/avec/avec_ma_eea.html

[34] The European Environmental Agency (EEA), www.eea.eu.int/

[35] The Millennium Ecosystem Assessment (MA), www.millenniumassessment.org

collaboration. EEA's Executive Director Jacqueline McGlade concluded that the new method of integrated ecosystem assessment, using scenarios and land-use accounting as the ATEAM, is the focus of a fresh set of EEA activities. Finally all participants discussed ways to best exchange the information produced by the ongoing assessment projects and the EEA, which plays a key role in improving the communication of scientific results to the policy arena and the larger public. Working with the EEA will be necessary to provide the foundation for better environmental management in Europe. Overall, the workshop was an exciting networking activity between policy advisors of the European Commission, EU-funded research activities like ATEAM and AVEC and European organisations like the EEA, as well as the global initiative MA.

6.2.4.4 Dialogue Evaluation

ATEAM's value for stakeholders

Stakeholder questionnaires and interviews of ATEAMers were carried out as part of the evaluation of the dialogue's outcome. Independent observers participated in each general stakeholder meeting and provided the stakeholder dialogue coordinators with interesting feedback. A detailed report on the dialogue evaluation was produced (as listed in Annex 2).

Stakeholders were in general satisfied with the amount of information provided prior to workshop events and had sufficient time to consult it. However, some respondents emphasised that documentation was sometimes too rough, too broad, or on the contrary too specific, as well as sent too late to fully understand the research focus and methods used.

Most stakeholders believed that the ATEAM workshops had been worth the time taken from their work (Figure 34), as well as overall relevant to their work (Figure 35). This was supported by informal feedback during the workshop, as well as by the readiness of many stakeholders to participate in more than one activity. Indeed 11 of the 47 stakeholders participated in at least two of the ATEAM dialogue activities. It should be nevertheless be noted that circa a fourth of all participants did not fill the questionnaire and might have given less positive responses.

Overall stakeholder appreciated the workshop contents and the topics covered by ATEAM's presentations. However some stakeholders emphasised that too many topics were covered during the events, which sometimes prevented to have an in depth discussion. Moreover some stakeholders mentioned that some topics had been treated in a too dispersed way so that the outcomes of specific discussion were too vague (e.g. on sectoral adaptive capacity and dissemination of the results).

Most stakeholders agreed that they had gained useful insights on European vulnerability to global change, some of which they would be able to integrate in their work (Figures 36 and 37). Fellow scientists and scientific/environmental advisers to the policy and management process were generally positive in the usability of the ATEAM results in their own research and work. In contrast, for many more professionally orientated stakeholders the actual model outputs, though interesting, were not suitable to specifically guide their strategic and daily decision-making and management practices. As awareness raising background information however, the ATEAM results were praised. The need to synthesise the research into clear messages and to target these to specific audiences was highlighted. Moreover the need for transparency was repeatedly brought forward, as stakeholders wanted to understand fully how ATEAM results were calculated, and which assumptions were made, in particular concerning policy and management.

Specific questions were asked to evaluate the quality of the interactions. Overall stakeholders believed that they had been comfortable enough to express their opinions and that their views had been adequately valued by all participants. Although it is possible that non-respondents may have felt otherwise, it appears that ATEAM has managed to develop an atmosphere of trust and friendliness in which positive comments and constructive criticism were encouraged and valued. Each session was moderated (generally by ATEAMers), which allowed most speakers to participate actively. It was however noted by some stakeholders that at times the moderators were not neutral enough and stepped in to "defend" the project rather than simply moderate the discussion.

Most stakeholders had been sufficiently interested in the project to consider participating in follow-up activities. Interest in future participation was motivated by the possibility to obtain more information on potential European vulnerability, as well as on sectoral adaptive capacity, and adaptation measures. All stakeholders wished to be kept informed of future activities and to received further information on the project final results. Many had already talked about ATEAM to colleagues or planned to do so.

The experience of the ATEAM stakeholder dialogue indicates that there is great scope for exchange and collaboration between scientists and stakeholders. The approach followed by ATEAM has been in general judged useful and relevant to stakeholders. Interest has been expressed for the vulnerability assessment methodology and the mapping tool developed by ATEAM. It was stressed that to increase the usability and clarity of the final ATEAM maps care should be taken to synthesise the most important take-home messages of these maps as well as clearly stating the assumptions and limitations involved in the modelling and the meaningfulness of the results at different scales.

Three key messages to summarise ATEAM's stakeholder dialogue experience are:

1. Research does not need to compromise on scientific rigour to be socially relevant.
2. The ATEAM assessment was made at a spatial resolution exceptionally high relative to many other global change vulnerability assessments (10'x10' grid resolution). Nevertheless, ATEAM results are more useful at European/national scale. It would be interesting to explore in future how modelling and dialogue methods can further help to address stakeholders' needs at sub-national scale and to further improve the integration and communication of scientific results.
3. It is critical to think, design, conduct and interpret vulnerability assessments following a (loose) participatory research approach as this contributes substantially in shaping scientific assessments, which are meaningful to potential end users. Without this, vulnerability assessments may remain a fascinating but very expensive abstract exercise.

Stakeholders influence on ATEAM

The indicators of ecosystem services that were estimated by the ATEAM modelling framework were chosen together with stakeholders from the list of indicators that the ecosystem model were able to produce. Mostly this choice was straightforward, such as choosing the indicator "wood production" for the forestry sector, and "run-off quantity and seasonality" for the water sector. However, in some cases we experienced surprises during the stakeholder interaction. For example, many stakeholders from the agricultural sector were less interested in crop yield estimates than they were in estimates of future agricultural area ("farmer livelihood"). Furthermore, additional indicators were found to satisfy stakeholders' interest in biomass energy production.

We also discussed the temporal and spatial scales of our analyses and received a diverse range of answers. For some stakeholders both the temporal (time slices 1990, 2020, 2050, 2080) and spatial scale (10'x10') were useful. Some wished to focus on long term developments (i.e. stakeholders from the forestry sector are concerned with 2080 and further), but the majority of stakeholders was more interested in short term estimates for the next five to ten years. For some stakeholders the spatial scale of the assessment was still too coarse, even though the resolution is already exceptionally fine for global change assessment. Especially stakeholders from regional nature conservation parks need more local information than the ATEAM was able to provide. Specific case studies would have been very welcome and ATEAMers were highly interested in conducting such research, but this plan could not be realised due to budget constraints.

ATEAM researchers learned especially how ecosystem services are recognised and managed by stakeholders. Within ATEAM considerable effort has been made to include management in the vulnerability assessment. For example decision-making in a socio-economic and policy context enters the assessment via the land use scenarios and via ecosystem models that take into account agricultural and forest management. Nevertheless a recurring theme during the dialogue was to learn just how complex human-environment interactions are in a context of EU, national and regional policies and under socio-economic constraints. To give one example, the diversity of forest ownership and forest use in terms of area owned, financial relevance relative to other income sources of the stakeholder and management goals was even greater than anticipated. Forest owners can rely on forest ecosystem services for almost all or next to none of their income, sometimes independent of the area of forest owned. Forests are managed to optimise many outcomes, ranging from commercial use, over recreational to spiritual meaning. Here our choice of indicators (i.e. wood production, carbon stored in vegetation and soil, species turnover, tree species distribution) fall short of the information needs of all possible stakeholders. These complexities were discussed during stakeholder interactions and explored especially in the land use modelling work. Two detailed reports on forest policy have been produced (Kankaanpää and Carter 2004ab, see Annex 2).

We conclude that our assessment was both valuable and useful for stakeholders and relevant in scientific terms. We also conclude that future analysis can be based on our concepts and results and for some sectors should especially target local scales and shorter time scales. Ecosystem modelling should continue to mature into human-environment-system modelling, by accounting for management and decision making in the socio-economic and policy context of the relevant stakeholders. This can be greatly facilitated by continued stakeholder interaction, making use of as well as advancing the tools and the stakeholder network developed in ATEAM.

6.2.5 Integrating potential impacts and adaptive capacity into maps of vulnerability (WP1, 5 and 6)

Principal investigators: Marc J. Metzger, Dagmar Schröter, Rik Leemans, Wolfgang Cramer

The term vulnerability stems from everyday language – the Oxford English Dictionary defines it as “the undesirable state of being open to attack or damage”. At the time the ATEAM proposal was submitted to the EU, researchers from different disciplines used the term ‘vulnerability’ intuitively as the risk of harm to something they, or somebody else values caused by global change. Since then, the concept of vulnerability has been debated in the scientific community, with considerable contributions by ATEAM researchers. By now a common definition of vulnerability, as well as an assessment concept have emerged (Turner et al. 2003, Schröter et al. 2004). ATEAM defines vulnerability as *the degree to which an ecosystem service is sensitive to global environmental change and the degree to which the sector that relies on the service is unable to adapt to the changes* (Metzger and Schröter 2004). Hence, potential impacts (the resultant of exposure and sensitivity) and adaptive capacity constitute a region’s vulnerability. Table 13 gives an overview of important terminology developed in ATEAM related to vulnerability, with examples for the sectors agriculture and carbon storage.

In Figure 38 we illustrate how the terms presented in Table 13 fit into the ATEAM vulnerability assessment. The future scenarios (exposure) feed into the ecosystem models, which determine future ecosystem service supply, i.e. potential impacts. The change in potential impacts compared to baseline conditions will be expressed in a stratified potential impact index. The socio-economic scenarios are translated into a generic adaptive capacity index, which can be combined with the potential impact index to map vulnerability.

Table 13. Definitions of important terminology related to vulnerability, with two examples.

Term		ATEAM definitions based on IPCC	Part of the assessment	Agriculture example	C-storage example
Exposure	**(E)**	The nature and degree to which the human-environment system is exposed to environmental change.	Scenarios	Increased climatic stress, decreases in demand	Increased demand, increased fire risk
Sensitivity	**(S)**	The degree to which a human-environment system is affected, either adversely or beneficially, by environmental change.	Ecosystem Models, Land Use Change Models, Adaptive Capacity Index	Agricultural ecosystems, communities and landscapes are affected by environmental change.	Ecosystems that store carbon are affected by environmental change.
Adaptation	**(A)**	Adjustment in natural or human systems to a new or changing environment.		Changes in local management, change crop	Changes in local management, change in tree species
Potential Impact	**(PI)**	All impacts that may occur given projected environmental change, without considering planned adaptation.	Ecosystem Models	Decrease in agricultural land area	Increase in storage
Planned Adaptation	**(PA)**	The result of a deliberate policy decision based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve a desired state.	Adaptive Capacity Index	More suitable agricultural management, e.g. switch to high quality safe products	More suitable fire management, e.g. change in land cover to less fire prone forests
Adaptive Capacity	**(AC)**	The potential to implement planned adaptation measures.	Adaptive Capacity Index	Capacity of more suitable agricultural management	Capacity of more suitable fire management
Vulnerability	**(V)**	The degree to which an ecosystem service is sensitive to global change plus the degree to which the sector that relies on this service is unable to adapt to the changes.	Vulnerability Assessment	Increased probability of yield losses through losses of agricultural area combined with inability to switch to save cash and quality crops	Increased probability of carbon losses through increased fire risk and inability to adapt to this by e.g. changing land cover to less fire prone forests (exchange Eucalyptus plantations with native forests)
Residual Impact	**(RI)**	The impacts of global change that will occur after considering planned adaptation.	The future will tell.	Farms 'giving up' despite efforts to adapt.	Carbon lost to forest fires despite adaptation strategy.

6.2.5.1 Stratification of potential impacts

For a meaningful comparison of grid cells across Europe it is necessary to place changes in their regional environmental context, i.e. in a justified cluster of environmental conditions that is suited as a reference for the values in an individual grid cell. Simply comparing absolute changes in ecosystem services across Europe without the regional environmental context provides only a limited analysis of regional differences. For instance, Spain has high biodiversity (5048 vascular plant species (WCMC 1992)), but low grain yields (2.7 t ha^{-1} for 1998-2000 average (Ekboir, 2002)), whereas The Netherlands has a far lower biodiversity (1477 vascular plant species (van der Meijden et al. 1996)), but a very high grain yield (8.1 t ha^{-1} for 1998-2000 average (Ekboir 2002)). While providing useful information about the stock of resources at a European scale, absolute differences in species numbers or yield levels are not good measures for comparing regional impacts between these countries. Expressing a relative change would overcome this problem (e.g. -40% grain yield in Spain versus + 8% in The Netherlands), but also has a serious limitation: the same relative change can occur in very different situations. Table 14 illustrates how a relative change of –20 % can represent very different impacts, both between and within environments. Therefore comparisons of relative changes in single grid cells must be interpreted with great care and cannot easily be compared.

We used the recently developed Environmental Classification of Europe (see next section) to put the results into their environmental context. The highest ecosystem service supply achieved within an Environmental Zone is used as a reference value (ESref, Table 14) to stratify potential impacts. Stratified potential impacts are calculated as the fraction of modelled ecosystem service value relative to the highest achieved ecosystem service value in that environmental zone, giving a value with a 0-1 range. Because the environmental context is altered by global change, consistent environmental strata are determined for each time slice, so that the ecosystem service reference value (ESref) changes over time. As shown in Figure 39, the stratified potential impact map shows more regional detail than the original potential impact map. This is the regional detail required to compare potential impacts across regions.

In addition to comparing regions, the change of stratified sensitivity potential impact over time can be seen by looking at three time slices through the 21st century, 2020, 2050 and 2080 relative to the 1990 baseline (Figure 39, third row of maps). The change in stratified potential impact compared to baseline conditions shows how changes in ecosystem services affect a given location. Regions where ecosystem service supply relative to the environment increases have a positive change in potential impact and vice versa. This change in potential impact is used to estimate vulnerability (see below).

Our method to express changes in potential impacts leads to a small risk of ‘false’ zero or positive change. If relative to the previous time slice the reference value decreases more than the modelled ecosystem service supply value for a grid cell, the stratified potential impact may stay the same or even increase. This is the case when the potential of an environmental zone to provide an ecosystem service decreases as a whole, but in a specific grid cell the modelled supply does not change very much so that it remains high or unchanged relative to the reference. This is what happens in grid cell B of environment 1 in Table 14. The environmental potential (indicated by the reference value ESref) decreases by 0.3, but the modelled value in the grid cell decreases only by 0.2, resulting in a change in potential impact of zero. This means at t and t+1 the same fraction of the reference value is supplied by the grid cell, even though the absolute supply of ecosystem service goes down. When interpreting maps of changing potential impacts or vulnerability, one needs to keep this rare case in mind. This is one of several reasons (discussed later) to look also at the constituting indictors separately when interpreting vulnerability of a region.

Table 14 Example of changing ecosystem service (grain yield in t ha^{-1} a^{-1}) supply in four grid cells and two different environments between two time slices (t and t+1). The potential to supply the ecosystem service decreases over time in environment 1 (green shading), and increases over time in environment 2 (blue shading). The "Value in a grid cell" is the ecosystem service supply under global change conditions as estimated by an ecosystem model. The relative change in ecosystem service may not form a good basis for analysing regional potential impacts, in this example it is always –20%. When changes are stratified by their environment, comparison of potential impacts in their specific environmental context is possible. The "Stratified potential impact" is the "Value in a grid cell" divided by the "Highest ecosystem service value" in a specific Environmental Zone at a specific time slice (see text). Note that there is a small risk of 'false' zero or positive change in potential impacts when the stratification is used (e.g. grid cell B, see text).

Environmental Zone	**environment 1**				**environment 2**			
Grid cell	**grid cell A**		**grid cell B**		**grid cell C**		**grid cell D**	
Time slice	**t**	**t+1**	**t**	**t+1**	**t**	**t+1**	**t**	**t+1**
Value in grid cell (t ha^{-1} a^{-1})	**3.0**	**2.4**	**1.0**	**0.8**	**8.0**	**6.4**	**5.0**	**4.0**
Absolute change (t ha^{-1} a^{-1})		**0.6**		**0.2**		**1.6**		**1.0**
Relative change (%)		**-20**		**-20**		**-20**		**-20**
Highest ecosystem service value, ESref (t ha^{-1} a^{-1})	**3.0**	**2.7**	**3.0**	**2.7**	**8.0**	**8.8**	**8.0**	**8.8**
Stratified potential impact, PIstr	**1.0**	**0.9**	**0.3**	**0.3**	**1.0**	**0.7**	**0.6**	**0.5**
Change in potential impact, ∆PI		**-0.1**		**0.0**		**-0.3**		**-0.1**

6.2.5.2 The Environmental Classification of Europe (EnC)

A new Environmental Classification of Europe (EnC) is used to interpret ecosystem service changes in their environmental context. The EnC was developed in 2002 (Figure 40; Metzger et al. 2004a, in collaboration with the Wageningen research institute Alterra[36]). This classification forms the spine of the Vulnerability Assessment framework for two reasons:

- It allows us to stratify potential impacts (see previous section; Metzger and Schröter 2004);
- It allows the Vulnerability Assessment framework to be applied in other studies at various scales (Metzger et al. 2004b).

The distribution of environmental zones shift with shifting environments. A specific discriminant function for each EnC class based on variables available form the climate change scenarios was created to calculate the distribution of each zone for future scenarios. Figure 41 shows how the Environmental Zones shift for one of the scenarios.

The UK Countryside survey (http://www.cs2000.org.uk/; Haines-Young et al., 2000) has shown how a statistically derived environmental classification can be used to integrate and summarize different forms of ecological data (e.g. field samples, satellite imagery, modelling results). Within ATEAM, climate and land use change scenarios were analysed using the EnC. Summarizing the scenarios per Environmental Zone makes differences in variability and trends in the scenarios across the European environment apparent, e.g. between Atlantic North and Mediterranean North (Figure 42). Similar

[36] Alterra - Alterra is part of Wageningen University and Research Centre and closely co-operates with the department of Environmental Sciences from Wageningen University. http://www.alterra.wur.nl/UK/organisatie/

summaries can be made for the changes in ecosystem services (Figure 43). Such summaries by Environmental Zone (13 in total), or even by Environmental class (84 in total) can be linked to other data sources or studies. Furthermore, the proposed classification can be used at different aggregation levels, and can be linked to global biome classifications. As a result, the vulnerability assessment framework is in principle applicable for many ecological studies (including field studies, modelling exercises and satellite monitoring), from local to global scales.

6.2.5.3 Vulnerability maps

Initially, the ATEAM project was designed to achieve a state-of-the-art potential impact assessment, using for the first time ever a consistent set of multiple global change drivers and multiple plausible future scenarios of these on a high spatial resolution to drive a framework of state-of-the-art ecosystem models. Owing to the new conceptual development from the beginning of the project, ATEAMers saw that this toolkit was two steps short of a global change vulnerability assessment. First, we lacked an indicator of the other essential constituent of vulnerability, namely *adaptive capacity*. And second, it was unclear how to combine changes in the potential impact indicators with adaptive capacity to obtain a measure of vulnerability. For both steps no ready made methodologies were available – the discipline of vulnerability assessment is so young that it finds or develops tools as it moves along. However, ATEAMers were determined to move beyond a mere impact assessment, toward an integrated vulnerability assessment of Europe with the tools that were at hand and those that we were able to develop during the project life-time. Therefore we have expanded our research commitment and have gone two steps further than originally planned. How we took the first step, characterising adaptive capacity, is described above (section *Modelling adaptive capacity*). In this section we describe the second essential step: how to combine anticipated changes in potential impacts with adaptive capacity to obtain a measure of vulnerability.

Empirical and theoretical evidence of how potential impacts and adaptive capacity can be combined into measures of vulnerability is very limited. Furthermore, as discussed above, the adaptive capacity index developed is preliminary. It represents regional, but not individual or national adaptive capacity. The adaptive capacity model used, unlike the ecosystem models, was not validated against observed data, because this is currently impossible. Therefore, we created a visual combination of changes in potential impact (ΔPI) and adaptive capacity (AC) without quantifying a specific relationship. The resulting vulnerability maps illustrate which areas are vulnerable in terms of high anticipated potential impacts and limited adaptive capacity. For further analytical purposes the constituents of vulnerability, the changes in potential impact and the adaptive capacity index have to be viewed separately.

Trends in vulnerability follow the trend in potential impact: when ecosystem service supply decreases, humans relying on that particular ecosystem service become more vulnerable in that region. Alternatively vulnerability decreases when ecosystem service supply increases. Adaptive capacity lowers vulnerability. In regions with similar changes in potential impact, the region with a high AC will be less vulnerable than the region with a low AC. The Hue Saturation Value (HSV) colour scheme is used to combine ΔPI and AC. The ΔPI determined the Hue, ranging from red (decreasing stratified ecosystem service supply; highest negative potential impact: $\Delta PI = -1$) via yellow (no change in ecosystem service supply; no potential impact: $\Delta PI = 0$) to green (increase in stratified ecosystem service supply; highest positive potential impact: $\Delta PI = 1$). Note that it is possible that while the modelled potential impact stays unchanged, the stratified potential impact increases or decreased due to changes in the highest value of ecosystem service supply in the environmental class (ESref). Thus, when the environment changes this is reflected in a change in potential impact.

Colour Saturation is determined by the AC and ranges from 50% to 100% depending on the level of the AC. When the ΔPI becomes more negative, a higher AC will lower the vulnerability, therefore a higher AC value gets a lower saturation, resulting in a less bright shade of red. Alternatively, when ecosystem service supply increases ($\Delta PI > 0$), a higher AC value will get a higher saturation, resulting in a brighter shade of green. Inversely, in areas of negative impact, low AC gives brighter red, whereas in areas of positive impacts low AC gives less bright green. The last element of the HSV colour code, the Value, was kept constant for all combinations. Figure 44 illustrates the approach based on wood production in the Forestry sector in 2080, considering climate and land use based on A1 HadCM3 . In the visual overlay, the relationship between ∆PI and AC is not specified beyond high ∆PI and low AC result in high vulnerability. Furthermore, the scale has no unit – the map identifies areas to guide further analyses of the underlying data.

Figure 45 shows a set of vulnerability maps based on the ecosystem service "Farmer livelihood", sector agriculture. The maps are based on changes in potential impacts on farmer livelihood relative to 1990 and the adaptive capacity index for the different scenarios and time slices (drivers were climate scenarios based on the general circulation model HadCM3 and the respective land use change for the storylines A1f, A2, B1, and B2). Do these maps provide useful information to answer the questions that drove our assessment (see introductory section *Background*):

- Which regions in Europe are most vulnerable to global change?
- Which scenario is the least harmful for a sector within Europe such as agriculture, forestry, etc.?
- Which sectors are the most vulnerable in a certain European region?

The maps depict the agricultural sector in the Mediterranean region as vulnerable under most scenarios starting at different time slices, depending on the scenario. The A scenarios anticipate greater vulnerability throughout. Different storylines represent different choices about our future socio-economic pathway. The B2 scenario seems to be least harmful for farmer livelihood. Comparing these maps with vulnerability maps for other sectors would yield answers to the third question, which sectors are most vulnerable in a specific region. Even though the vulnerability maps indicate some answers to the questions above, the answers remain unspecific. Further analyses of the underlying indicators is necessary to understand possible causes of vulnerability, to analyse results in terms of absolute changes. The conclusions we draw from our research project are rather based on a thorough analyses of potential impacts than on the final vulnerability maps alone (see below).

Vulnerability is a dynamic outcome of both environmental and social processes occurring at multiple scales (O'Brien et al. 2004). When the maps of vulnerability presented here depict problematic regions, further attention should be directed to these regions to analyse their vulnerability in the context of nested scales and on higher and lower resolution than the 10'x10' latitude longitude grid. The vulnerability maps show vulnerable areas per sector and ecosystem service, and per future time slice. Currently no model of the human-environment system exists that reflects all the interactions between ecosystem services and sectors for a range of nested scales. The ATEAM vulnerability maps are therefore not maps of total European vulnerability, but of essential aspects constituting the overall vulnerability. These maps can be used to anticipate vulnerability of different sector based on specific ecosystem services, as a basis for discussion of interactions between these sectors and ecosystem services. For example, as stakeholders from the carbon storage sector have pointed out, planting forests to sequester carbon has implications for the aesthetic value of a landscape, and therefore for the tourism sector, as well as for the runoff in a particular region, and therefore for the water sector. In our vulnerability mapping tool all ecosystem services are presented in a common dimension which facilitates the examination of such interactions.

In this vulnerability assessment, the supply of ecosystem services is used as a measure of human well-being under the influence of global change stressors, similar to the approach suggested by Luers et al. (2003). Perceived well-being, as well as anticipated vulnerability, is always based on a value judgement. Stakeholders from different sectors may base their value judgement on different assumptions – in other words, some aspects of vulnerability are individual. In our stakeholder dialogue, it became apparent that many stakeholders are rather interested in potential impacts than in generic vulnerability maps. Stakeholders used their individual values to judge the severity of a potential impact. Furthermore, stakeholders often wished to account for their own individual adaptive capacity when interpreting potential impacts. The generic adaptive capacity index we developed may have informed them of the socio-economic context in which they might operate in the future. However, their anticipated future ability to adapt to change was a matter of personal perception. In a flood prone area in Germany it has recently been shown that "perceived adaptive capacity" is a major determinant of whether people will take adaptation measures or not (Grothmann and Reusswig 2004). It seems that more place based studies could better take account of the individual nature of vulnerability.

The current framework was developed with the tools at hand and a wish list of analyses in mind. Strong points in the framework are the multiple scenarios as a measure of variability and uncertainty, the multiple stressors (climate, land use, and nitrogen deposition change), the stakeholder involvement, and the inclusion of a measure of adaptive capacity. The approach, as presented here, will facilitate the analysis of the ecosystem services estimated by ecosystem models. As the approach is applied, more advanced methods of combining changes potential impact (ΔPI) and adaptive capacity (AC) may be developed, i.e. through fuzzy logic or qualitative differential equations (cf. Petschel-Held et al. 1999). However, prerequisite for this is a further understanding how ΔPI and AC interact and influence vulnerability, which may only be feasible when analysing specific cases. Ideally the AC index will eventually be replaced by sector specific projections of adaptive capacity. Some qualitative information, or knowledge shared during stakeholder dialogues does not enter the approach in a formal way. Therefore it is imperative to discuss the results with stakeholders, experts and scientists as part of the analysis.

To facilitate this discussion, and the analyses of underlying interactions and causes of anticipated vulnerability, the ca. 3200 maps and charts produced in ATEAM will be disseminated in form of a digital atlas, the interactive ATEAM mapping tool. The atlas contains maps of vulnerability, as well as the underlying indicators, such as exposure, potential impact and adaptive capacity. In this tool, sectors, ecosystem services, scenarios and time slices can be selected and maps and summarising charts will be given on demand. Customised comparison of different scenarios, sectors, services and/or time slices is possible. Results can also be summarised by country or environmental zone. Each map and chart is accompanied by careful documentation of the underlying assumptions and an outline of the selected future scenario. A brief summary of each result shown is provided to prevent misunderstandings. This digital atlas is currently finalised and will be released soon, a demo version has already been tested at the last big stakeholder dialogue workshop. Figure 46 illustrates the welcoming screen – the preliminary nature of this version is indicated by the typo in the on-screen illustration of "Biodiversity".

6.3 Conclusions including socio-economic relevance, strategic aspects and policy implications

- **Vulnerable region:** In comparison between regions, the Mediterranean seems most vulnerable within Europe. Multiple potential impacts on multiple sectors were projected. These include water shortages especially in the summer months when demand peaks due to tourism, increased fire risk in the forestry sector, losses in the carbon storage potential, northward shifts in the distribution of tree species like maritime pine and cork oak, and losses of agricultural potential due to drought. These potential impacts combine with low adaptive capacity (based on a socio-economic regional scale generic index).
- **European agricultural sector:** Land use change projections based on socio-economic and climatic changes project an overall decline in arable land (cropland, grassland) in Europe. This results in “surplus land”. It is unclear what could happen to these areas of surplus land, although it seems that continued urban expansion, recreational areas and forest land use would all be likely to take up at least some of the surplus. This assumes, however, that the pressures toward declining agricultural areas are counterbalanced by policy mechanisms that seek to limit crop productivity. This could include measures to promote (a) extensification[37] or organic production (particularly consistent in the environmental scenarios), (b) the substitution of food production by energy production and the planting of trees, or an acceptance of overproduction (as with the current EU’s CAP[38]). European land demand for biomass energy crops may go up. When biomass energy products are used for energy production instead of fossil fuels, less carbon dioxide per unit energy produced is released. To make use of this climate protection potential, shifts in areas suitable for biomass energy crops related to climate change should be taken into account. The suitable area for some crops expands. However, some current agricultural areas become too hot and too dry to support agriculture for any crop type. Furthermore a climate driven decline in soil fertility is expected (indicated by soil organic carbon losses) in some areas. This negative trend is only partly counteracted by land use changes and stimulated plant growth and calls for increased attention to management practises that sustain soil fertility
- **European forestry sector:** Land use change scenarios indicate an increase in forest area under all but one socio-economic scenario. Climate change is anticipated to have an overall positive effect on growing stocks in Northern Europe. However, negative effects were projected in other regions, e.g. drought and fire pose an increasing risk to Mediterranean forests. The distribution of some tree species is projected to change, e.g. cork oak, holm oak, aleppo pine and maritime pine. Management seems to have a greater influence on the development of the growing stock and forest productivity than climate or land use change. When forest resources are not fully utilised, the age-class distribution shifts towards old and unproductive forests, while intensive, sustainable forest management keeps the net annual increment at a high level.
- **European terrestrial carbon balance:** Europe‘s terrestrial biosphere currently acts as a small carbon sink. Despite considerable regional differences all scenarios show a weakening of this carbon sink after 2050. This trend is the net result of positive effects of land use change (i.e. reforestation) and negative effects of climate change on the Europe wide terrestrial carbon balance (considering all types of land uses, e.g. crop and grassland as well as forests). While European forest trees accumulate carbon, the soils of boreal forests may loose more carbon than the trees take up. Furthermore drought stress and increased fire risk in Mediterranean leads to increased carbon fluxes to the atmosphere. The relative importance of positive forest management effects on carbon stored in Northern forests for the Europe wide carbon balance is currently under debate.

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[37] Extensification – The transition of a land cover or land use type associated with high intensity of use to a lower intensity of use (e.g. improved grassland to semi- natural cover).

[38] EU’s CAP – The Common Agricultural Policy of the European Union.

- **European water sector:** Despite considerable regional differences, there is some broad consistency in the pattern of projected change – reductions in runoff in southern Europe and increases in northern Europe. Reductions in 30-year mean runoff in parts of southern Europe can be as great as 30%. Climate change tends to increase the numbers of basins in southern Europe with water scarcity (i.e. water availability per capita falls below 1000 m^3 $capita^{-1}$ $year^{-1}$). Climate changes have a much greater impact on runoff than land use changes in the catchments. At least under one climate model, climate change may produce simultaneously more severe droughts and more extreme floods in some areas of northwestern Europe. Large reduction in maximum flows in eastern Europe is mainly due to the shift in timing of flows from spring to winter, as a greater proportion of precipitation falls as rain rather than snow. Case studies for Rhine, Rhone and Danube indicate that changes in the timing of river flows, largely due to the reduction in the amount of snowfall and hence spring snowmelt, will affect both navigation and run-of-river hydropower potential. The reduction of water storing snow cover is expected to have a profound impact on the Alpine stream flow pattern. Currently, most of the major floods in the Alpine area occur in summer. Model results indicate that this summertime characteristic will shift towards or even into the winter half year as all scenarios produce a decrease in summer stream flow, an increase in winter stream flow and a shift of monthly peak flow to earlier dates. As a consequence, winter floods will become more frequent, and in lower lying Alpine catchments they might even become more common than summer floods under a warming climate.
- **Biodiversity and nature conservation in Europe:** Projections of occurrence of more than 2000 species across Europe (1350 plants, 157 mammals, 108 herptiles (reptiles and amphibians) and 383 breeding birds) for 2080 show great sensitivity of biodiversity under all climate change scenarios. The A1f (economic, global, fossil fuel intensive) represents the most threatening scenario for species diversity with some regions expected to lose more than 80% of current species richness. This scenario also produces the greatest variability across Europe, while B1 (environmental, global) appears to produce the lowest species loss and species turnover by pixel. Hot spots of expected biodiversity change were the Iberian Peninsula, Central Europe, and Scandinavia. The ranking of regional sensitivities was consistent across scenarios. The detailed examination of the projections for plants in 2050 under the full dispersal hypothesis revealed that 93% of species were projected to have overlapping populations with current distributions, while 2% had totally non-overlapping future distributions and 5% lost all available habitat. These changes meant that, over a range of reserve selection methods, 6% to 11% of species modelled would be potentially lost from selected reserves in a 50-year period. The modeling framework used here was developed to allow reserve area selection to optimize the protection goal of nature conservation areas under restricted resources and changing climate. This framework could support the flexible management of nature reserve areas which is necessary to maintain the conservation effect under changing environmental conditions.
- **European mountain tourism:** Snow cover, an indispensable prerequisite for winter tourism, is highly sensitive to changes in temperature. Simulations indicate that the elevation of a reliable snow cover will rise between 200 m and 400 m, i.e. from about 1300 m a.s.l. today to 1500-1700 m a.s.l. at the end of the 21st century. The predicted increase in winter precipitation can partly compensate for the temperature-related rise of the snow line, but it cannot prevent the upward shift. At present, about 85% of all Swiss ski areas still have sufficient snow. A 300 m rise of the snow line, however, would reduce this to about 63%. Sensitivity studies for the five catchments have shown that the elevation of reliable snow cover moves upward by approximately 150 m per degree Celsius of warming. An analysis of the number of summer heat days revealed that particularly in the southern Alps heat days become more frequent, which likely reduces the attractiveness of this area for a range of outdoor activities such as hiking or biking and also increases the number of mountaineering accidents. Hence, mountain tourism may be impacted negatively in both winter and summer.

- **Stakeholder dialogue:** The ATEAM dialogue between scientists and stakeholders is an important part of the results. It was our continuous effort to keep this dialogue informed by best science, fair, and focused. The project collaborated with an expanding stakeholder network. The assessment approach was continuously being reviewed in this dialogue. To promote sustainable environmental management in Europe it would be best if this dialogue were sustained beyond the lifetime of this project. We are confident that many scientists and stakeholders who participated in our dialogue would agree that this activity should go on, improved by professional moderation and a permanent platform for exchange and discussion.
- **Vulnerability concept:** Not least from our interactions with stakeholders we conclude that aggregated measures of vulnerability are of limited value. In our integrated assessment they came to serve as a way to alert us to regions or sectors that were then analysed further by consulting the underlying data. Often information on potential impacts will be sufficient to stakeholders who conclude about vulnerability using knowledge about their own adaptive capacity and their individual values.
- **Facilitating sustainable management:** The full range of environmental impact scenarios from our pan-European assessment provides spatially explicit projections of ecosystem services over time, while being honest about the attached uncertainties. The framework was applied to determine the vulnerability of human sectors that rely on ecosystem services with respect to global change. A dialogue with stakeholders continuously guided the assessment process. The ability of human sectors to implement planned adaptation measures was taken into account by introducing indicators of adaptive capacity to our vulnerability approach. The results add to the basis for discussion between different stakeholders and policy makers, thereby facilitating sustainable management of Europe's natural resources under global change.

6.4 Dissemination and exploitation of the results

One of the main products is the ATEAM digital atlas on CD-ROM with the interactive ATEAM mapping tool displaying the full range of charts and maps of our results with exhaustive documentation and summarised conclusions per mapped result. This product is targeted mostly at a non-scientific audience like stakeholders and policy makers. The tool is currently finalised and will be distributed to our stakeholder network, and beyond. We are currently looking for a permanent institution to archive this tool for further dissemination and future development. This institution may possibly be the European Environment Agency (EEA) in Copenhagen, Denmark.

Another main product of ATEAM is targeted at the scientific community of vulnerability and global change research. This is a journal special issue with five scientific papers to be published probably by peer-reviewed Springer journal *Regional Environmental Change*. The following papers are currently being prepared to appear in this special issue (1) Mapping Vulnerability to Global Change, (2) European ecosystem services and global change, (3) European vulnerability to changes in ecosystem services, (4) A stakeholder dialogue on European vulnerability, and (5) Data and scenarios for vulnerability mapping of Europe. In addition to this special issue, numerous papers have been and will still be published as a result from the ATEAM project (see Annex 2).

The ATEAM has produced a number of large datasets in form of observed and projected variables related to the environment and society. This includes data on climate, land use, land cover, nitrogen deposition, soils, carbon fluxes, and socio-economic variables. These datasets are distributed through our ATEAM website hosted at the Potsdam Institute for Climate Impact Research (PIK). We are currently looking for a permanent institution to archive these data for further dissemination and future development. This institution may possibly be the European Environment Agency (EEA).

The stakeholder workshops and their documentation were another means of dissemination. ATEAMers conducted six ATEAM stakeholder workshops and contributed to eight events targeted at stakeholders that were organized outside the project. During and after these workshop ATEAMers had several press contacts and our results were disseminated through national (e.g. Süddeutsche Zeitung) and local (e.g. Berliner Zeitung) newspapers as well as targeted magazines (e.g. Trail Magazine).

ATEAM has contributed to an international summer school on Vulnerability Assessment. Ca. 30 graduate and post-graduate students have discussed and used ATEAM concepts and results to learn about vulnerability assessment and to develop their own approaches and tools.

ATEAMers contribute to the first reports of the Millennium Ecosystem Assessment (see Annex 2) and to a book project of the Environmental Vulnerability Assessment group at the Potsdam Institute for Climate Impact Research (PIK, see Annex 2).

The ATEAM websites were built and maintained and will be hosted at PIK until at least the end of 2004.

6.5 Main literature produced

Further publications are listed in Annex 2.

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Annex 1 - Conferences and meetings

1.1 Organised and co-organised meetings

2004

- *The third and final ATEAM stakeholder dialogue: Vulnerability of European sectors to global changes*. May 3-4, 2004, Potsdam, Germany.
- The final annual ATEAM meeting. April 30-31 2004, Annot, France. ATEAM internal.
- The Synthesis Group Meeting. April 29 2004, Annot, France. ATEAM internal.
- *Environmental Vulnerability Assessment for Policy and Decision-Making - The final EVA ToPIK workshop*. May 17-18, 2004, Potsdam University, Neues Palais, Potsdam, Germany.
- *Second International Conference on Climate Impacts Assessment (SICCIA)*, joint event of the NOAA Office of Global Programs, the Climate Impacts Group (University of Washington), and the US National Science Foundation, June 28-July 2, 2004, Grainau, Germany.

2003

- *The second annual ATEAM meeting*, May 5-8, 2003, Evora, Portugal. ATEAM internal.
- *Vulnerability assessment*. Working meeting. March 6-7, 2003. Wageningen, The Netherlands. ATEAM internal.
- *Adaptive capacity meeting*. Wageningen, The Netherlands, April 24-25, 2003. ATEAM internal.
- CarboEurope greenhouse gas (GHG) meeting on Cropland and Grassland GHG fluxes, Sept 4-6 2003, Clermont-Ferrand, France.
- *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France.
- ESF Workshop: *Methods for the detection of changes in soil carbon stocks under climate change*, Oct 29-31, 2003, Edinburgh, Scotland.
- *Sustainable Forest Management Indicators: Application and Research at the Universitat Autònoma de Barcelona (Bellaterra, Barcelona)* (*Indicadors de Gestiô forestal sostenible: aplicaciô i recerca*). CREAF (Centre de Recerca Ecològica i Aplicacions Forestals, Spain), Dec 11, 2003, Barcelona, Spain.
- Telephone conference ATEAM synthesis group, Nov 11, 2003. ATEAM internal.
- Steering committee telephone conference, Feb 4, 2003. ATEAM internal.
- Steering committee telephone conference, March 4, 2003. ATEAM internal.
- Steering committee telephone conference, March 28, 2003. ATEAM internal.
- Steering committee telephone conference, Sept 2, 2003. ATEAM internal.
- Steering committee telephone conference, Nov 5, 2003. ATEAM internal.
- steering committee telephone conference, Dec 2, 2003. ATEAM internal.

2002

- ATEAM land use scenario development meeting, January 9-10, 2002, Louvain-la-Neuve, Belgium. ATEAM internal.
- Sectoral stakeholder meeting: Agriculture and Biofuels, February 5, 2002, Paris, France.
- Benchmarking of ATEAM biogeochemistry models and LPJ consortium workshop, March 25-27, 2002, Potsdam, Germany. ATEAM and LPJ internal.
- Meeting with the Royal Society for the Protection of Birds (U.K.), March 2002, CEFE.
- The 1st annual ATEAM meeting, April 15-17, 2002, Barcelona, Spain. ATEAM internal.
- ATEAM steering committee meeting, May 10, 2002, Durbuy, Belgium. ATEAM internal.
- AVEC Kick-off and networking with ATEAM meeting, May 16-17, 2002, Basel, Switzerland.
- Global change research and Eastern European candidate countries, an introductory meeting with Polish colleagues, June 3-4, 2002, Poznan, Poland.

- Visit to the Swiss Federal Institute for Forest, Snow and Landscape Research, Zürich, May 2002. Discussion of the Swiss case study, CEFE.
- ATEAM scenario development meeting, July1-2, 2002, Helsinki, Finland. ATEAM internal.
- ATEAM vulnerability assessment workshop, July 10-11, 2002, Potsdam, Germany. ATEAM internal.
- Panel discussion on vulnerability with Bill Clark, Sheila Jasanoff, John Schellnhuber and Carlo Jaeger, July 15, 2002, Potsdam, Germany.
- Second workshop on climate change and reserve selection for biodiversity, July 2002. Sponsored by the Centre for Applied Biodiversity Research (Conservation International, Washington DC). Location: 'Conventinho da Mitra, Universidade de Évora'.
- ATEAM preparatory meeting for the 2nd ATEAM stakeholder workshop, September 10, 2002, Potsdam, Germany. ATEAM internal.
- 2nd ATEAM stakeholder workshop, September 11-12, 2002, Potsdam, Germany.
- Vulnerability Methods and Models Workshop, October 16-18, 2002, John F. Kennedy School of Government, Harvard University, Boston, USA.
- Modelling land use change (MODLUC). A European Commission Advanced Study School, Louvain-la-Neuve, October 27 – November 3, 2002. (Rounsevell)
- ATEAM steering committee meeting, Oktober 21-22, 2002. Isle-sur-la-Sorgue, France. ATEAM internal.
- ATEAM - Mountain Stakeholder Workshop, November 4-5, 2002, Kappel am Albis, Switzerland.
- Environmental Vulnerability Assessment (EVA) Meeting. November 19, 2002, Potsdam, Germany.
- ATEAM Adaptive Capacity and Vulnerability Meeting, November 21-22, 2002, Louvain-la-Neuve, Belgium. ATEAM internal.
- Workshop on bioclimatic modelling on species distributions, November14, 2002. Sponsered by: Center for Applied Biodiversity Research (CABS), Conservation International (CI), Washington DC; and the European Union ATEAM project, Hosted by: Centre d'Ecologie Fonctionnelle et Evolutive (CEFE), Centre Nationale de la Recherche Scientifique (CNRS).
- Workshop of the EU project INTEGRATION. November 25-26, 2002, Potsdam, Germany.
- ATEAM steering committee telephone conference. November 6, 2002. ATEAM internal.
- ATEAM steering committee telephone conference. December 3, 2002. ATEAM internal.
- Meeting of Forestry Sector of ATEAM, December 19- 20, Wageningen, Netherlands. ATEAM internal.

2001

- ATEAM kick-off meeting, March 5th-7th, 2001. Potsdam Institute for Climate Impact Research, Potsdam, Germany.
- ATEAM Biogeochemistry work package meeting, May 16th and 17th 2001, Paris France.
- International vulnerability workshop, September 28th-30th, 2001. “Methods and Models of Vulnerability Research, Analysis and Assessment Workshop”, Potsdam Institute for Climate Impact Research, Potsdam, Germany.
- ATEAM Stakeholder workshop, 22nd - 24th Oct. 2001. “Initiating the ATEAM Dialogue: 1st ATEAM Stakeholder Workshop” Isle-sur-la-Sorgue, France.
- Internal ATEAM meeting, 21st and 24th Oct. 2001. “Preparing and evaluating the 1st ATEAM Stakeholder Workshop” Isle-sur-la-Sorgue, France.

1.2 Conference attendance

2004

- *Second International Conference on Climate Impacts Assessment (SICCIA)*, joint event of the NOAA Office of Global Programs, the Climate Impacts Group (University of Washington), and the US National Science Foundation, June 28-July 2, 2004, Grainau, Germany. (Dagmar Schröter)

- Gaia and Global Change, June 2004, Dartington Hall, UK. (Colin Prentice)
- Twentieth sessions of the subsidiary bodies (SB 20), United Nations Framework Convention on Climate Change (UNFCCC), *Workshop on Scientific, Technical and Socio-Economic Aspects of Impacts of, Vulnerability and Adaptation to Climate Change*, June 16-25, 2004, Hotel Maritim, Bonn, Germany. http://unfccc.int/sessions/workshop/180604/present.html (Dagmar Schröter)
- *Workshop on Global Change and the Future of Ecosystems in Europe,* sponsored by AVEC (EU-Concerted Action *Integrated Assessment of Vulnerable Ecosystems under Global Change*), EEA (*The European Environment Agency*) and MA (*The Millennium Ecosystem Assessment*), June 10-11, 2004, European Environment Agency, Copenhagen, Denmark. (Wolfgang Cramer, Anne C. de la Vega-Leinert, Rik Leemans, Marc J. Metzger and Dagmar Schröter)
- Environmental Science Section (ESS) Kalmar University Symposium, *Climate risk and vulnerability – exploring conditions for ecological and societal adaptation,* June 7-9, 2004, Kalmar, Sweden. (Dagmar Schröter)
- Environmental impacts of global change. British Ecological Society/European Ecological Federation Annual Symposium, *Ecology without frontiers: Environmental challenges across Europe*, Exeter University, April 5-7, 2004, Exeter, UK. (Dagmar Schröter)
- *Environmental Vulnerability Assessment for Policy and Decision-Making - The final EVA ToPIK workshop*. May 17-18, 2004, Potsdam University, Neues Palais, Potsdam, Germany. (Wolfgang Cramer, Anne C. de la Vega-Leinert, Richard Klein, Rik Leemans, Dagmar Schröter, Sönke Zaehle)
- *Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Multi-Scale Assessments*, organised by the Millennium Ecosystem Assessment, March 17-20, 2004, Alexandria, Egypt. (Marc J. Metzger)
- *European Geosciences Union, 1st General Assembly,* April 25 – 30, 2004, Nice, France. (Sönke Zaehle)

2003

- *Annual meeting of the Society for Experimental Biology*, April 2003, Southampton, UK. (Santi Sabaté and Carlos Gracia)
- *VII Congreso Nacional de la Asociación Española de Ecología Terrestre*. July 2–4, 2003, Barcelona, Spain. (Santi Sabaté, Carlos Gracia, Eduard Pla, Jordi Vayreda and Anabel Sánchez)
- 3rd Meeting of Environmental Policy Departments of EU-Member States' Foreign Ministries *Confidence Building Measures by the EU on International Climate Change.* Deutsches Auswärtiges Amt (German Foreign Ministry), May 15-16, 2003, Berlin, Germany. (Dagmar Schröter)
- *Global Climate Change and Biodiversity Conference*. Tyndall Centre for Climate Change Research, University of East Anglia, April 8-10, 2003, Norwich, UK. (Dagmar Schröter)
- *Wald und Wasser*, Conference, Feb 26, 2003, Gurten, Switzerland. (Bärbel Zierl)
- *Mountain Hydrology Workshop*, April 2- 4, 2003, Einsiedeln, Switzerland. (Bärbel Zierl)
- *European Geophysical Society*, April 7 – 11, 2003, Nizza, France. (Bärbel Zierl)
- *Carbon Sequestration in European Grasslands*, COST Action 627, Clermont-Ferrand, France, 7 September 2003. (Pete Smith)
- *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC)*. Sept 14-27, 2003, Peyresq, France. (Wolfgang Cramer, Mark Rounsevell, Rik Leemans, Anne de la Vega-Leinert, Marc Metzger, Sönke Zaehle, Dagmar Schröter, Pete Smith, Tim Carter, Pytrik Reidsma, Pablo Morales)

- *CArbon Sequestration potential in different Belgian Terrestrial ECosystems: quantification and strategic exploration*, Oct 2003, University of Gent, Belgium. (Pete Smith)
- *Land- und Forstwirtschaft als Senken für atmosphärischen Kohlenstoff in Deutschland: Prozesse, Datenbedarf und Handlungsoptionen*, Nov 2003, Braunschweig, Germany. (Pete Smith)
- *European greenhouse gas budgets of the biosphere,* COP 9 Side event , Dec 10, 2003, Milano, Italy. (Wolfgang Cramer and Pete Smith)
- *V World Parks Congress*, Workshop Stream VII *Building a Comprehensive Protected Area System*, IUCN, Sept 8-17, 2003, Durban, South Africa. (Miguel Araújo)
- *The biofuels directive: potential for climate protection*, Biofuels conference, European Climate Forum, Tyndall Centre, UEA, Sept 8-10, 2003. (Joanna House)
- *Climate uncertainty, Long-Term Goals, and Current Mitigation Effort*, Massachusetts Institute for Technology (MIT) Global Change Forum XXI, Oct 8-10, 2003, Boston, Massachusetts, USA. (Wolfgang Cramer, Dagmar Schröter)
- *A view into PIK's future – Scientific perspectives in the area around Berlin and Brandenburg*. 2nd ToPIK workshop, Sept 11-12, 2003, Potsdam, Germany. Reviewing of research sketches. (Wolfgang Cramer, Dagmar Schröter)
- *Fifth plenary meeting of COST E21 The role of forest for mitigating greenhouse gas emissions*, Nov 27 - 29, 2003, Thessaloniki, Greece. (Jari Liski)
- *CarboEurope Conference The continental carbon cycle*, March 19-21, 2003, Lisbon, Portugal. (Jari Liski)
- *International Association for Landscape Ecology World Congress,* July 13-17, 2003, Darwin, Australia. (Marc Metzger)
- *Brainstorm workshop EU 5th framework programme BioHab (EVK2-2001-00362),* Nov 12 –14, 2003. Wageningen, The Netherlands. (Marc Metzger)
- *The Young Landscape Ecologist Workshop*, Dec 11, 2003, Utrecht, The Netherlands. (Marc Metzger)
- *Framing Land Use Dynamics*, Utrecht International Conference, April16-18, 2003, Utrecht, The Netherlands. Presentation. (Isablle Reginster)
- *EGS - AGU - EUG Joint Assembly*, April 6 – 11, 2003, Nice, France. (Wolfgang Cramer, Alberte Bondeau, Stephen Sitch and Kirsten Thonicke)

2002

- Internal MONARCH project meeting, March 2002, Oxford, U.K. (Araujo)
- ESF Exploratory Workshop: Trophic Interactions in a Changing World, 3-7 April 2002 Texel, The Netherlands. (Schröter)
- SilviStrat annual meeting, April 26-27, 2002, Kloster Zinna, Germany. (Schröter, Erhard, Zaehle)
- Third LPJ Development Workshop, May 7-11, 2002, Durbuy, Belgium. (Cramer, Prentice, Sykes, Smith, Sitch, Schröter, Thonicke)
- ATEAM, the Millennium Ecosystem Assessment and the European Environment Agency meeting, May 27, 2002, Kopenhagen, Denmark. (Schröter)
- ESF Workshop: The Functional Significance of Forest Diversity, June 13-15, 2002, Weimar, Germany. (Cramer, Schröter)
- Meeting of the British Society of Soil Science (BSSS) on 'Soils as Carbon Sinks: Opportunities and Limitations', The Scientific Societies Lecture Theatre, June 28, 2002, London, UK. (Smith, Glendining)
- ICTP Conference on Detection and Modeling of Regional Climate Change. The Abdus Salam International Centre for Theoretical Physics. October 1-2 2002, Trieste, Italy. (Cramer)
- Modelling vulnerability and adaptation, Meeting at NOAA, Oct. 3, 2002, Washington DC, USA. (Schröter)

- Land use and agriculture in Europe: framing an EEA land use change scenario exercise, EEA, Nov. 25-26, 2002, Copenhagen, Denmark. (Rounsevell)
- European Research 2002 - The European Research Area and the Framework Programme, Nov. 11-13, 2002, Brussels, Belgium. (Cramer, Schröter)
- The Potsdam Institute for Climate Impact Research ToPIK Days, December 17-18, 2002, Potsdam, Germany. (Cramer, de la Vega-Leinert, Klein, Sitch, Schröter)
- IV International Conference on Forest Fire Research, Nov 18-22, 2002. Luso, Portugal. (Espineira, Thonicke)

2001

- Workshop, 8th-12th April, 2001. “The Second LPJ Development Workshop” Durbuy, Belgium (Cramer, Schröter).
- Workshop, May 29th-June 1st, 2001. “Research and Assessment Systems for Sustainability Summer Study”, Airlie House, Warrenton, Virginia, USA. (Cramer, invited by Harvard University)
- Open Science Conference, 10-13 July, 2001. “Challenges of a changing world”, Amsterdam, The Netherlands. (Schröter)
- Conference, 24-26 Oct. 2001, “International Conference Carbon Sinks and Biodiversity”, Liege, Belgium. (Reginster)
- Conference, 10th November 2001. “Cellular Automata, Neural Networks and Multi-Agent Systems in Urban Planning”, Milan, Italy. (Caruso)
- European Phenology Network Conference, 5-7 Dec. 2001. “The times they are a-changin' -- Climate change, phenological responses and their consequences for biodiversity, agriculture, forestry and human health”. Wageningen, The Netherlands. (van der Werf)
- Workshop, 2-8 December, 2001. “Global Change and Water Resources in the Mediterranean Region”, Toledo, Spain. (Schröter)

Annex 2 - Publications

2.1 Peer reviewed publications

2.1.1 2004 special issues, CD-ROM and book projects

2.1.1.1 Special issue for the journal *Regional Environmental Change*

The ATEAM is currently preparing a special issue for the journal *Regional Environmental Change* entitled “A European Global Change Impact and Vulnerability Assessment”. Papers are listed in order of appearance in the issue:

1. Cramer, W. et al. 2004. Mapping Vulnerability to Global Change. To be submitted to *Regional Environmental Change* in an ATEAM Special Issue. In preparation.
2. Schröter, D. et al. 2004. European ecosystem services and global change. To be submitted to *Regional Environmental Change* in an ATEAM Special Issue. In preparation.
3. Metzger, M.J. et al. 2004. European vulnerability to changes in ecosystem services. To be submitted to *Regional Environmental Change* in an ATEAM Special Issue. In preparation.
4. De la Vega-Leinert, A.C. et al. 2004. A stakeholder dialogue on European vulnerability. To be submitted to *Regional Environmental Change* in an ATEAM Special Issue. In preparation.
5. Erhard, M. et al. 2004. Data and scenarios for vulnerability mapping of Europe. To be submitted to *Regional Environmental Change* in an ATEAM Special Issue. In preparation.

2.1.1.2 The ATEAM mapping tool – an interactive CD-ROM

Metzger, M.J., R. Leemans, D. Schröter, W. Cramer and the ATEAM consortium. The ATEAM vulnerability mapping tool. Quantitative Approaches in Systems Analysis No. 27, CD-ROM publication, Office C.T. de Wit Graduate School for Production Ecology & Resource Conservation (PE&RC), Wageningen, The Netherlands, 2004.

2.1.1.3 Contributions to the first report of the *Millennium Ecosystem Assessment* (MA)

The Millennium Ecosystem Assessment (MA) is an international work program designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes. The MA is governed by a Board comprised of representatives of international conventions, UN agencies, scientific organizations and leaders from the private sector, civil society, and indigenous organizations. A 13-member Assessment Panel of leading social and natural scientists oversees the technical work of the assessment supported by a secretariat with offices in Europe, North America, Asia, and Africa and coordinated by the United Nations Environment Programme. More than 500 authors are involved in four expert working groups preparing the global assessment and hundreds more are undertaking more than a dozen sub-global assessments. The technical assessment reports produced by each of the MA working groups have entered the peer review stage and will be published in early 2005. A number of ATEAMers contribute to the MA and to its reports. The MA is preparing three reports, namely “The Conditions and Trends Assessment (CTA)”, “The Scenarios Assessment (SA)” and the “Responses Assessment (RA)”:

- Rik Leemans is Working Group Co-Chair of "The Responses Assessment (RA)”, coordinating lead author of chapter 0 *A Prologue to Responses for Ecosystems and Human Well-being* in RA, and contributing author to *Responses to Climate Change* in RA
- Wolfgang Cramer is Lead Author of Chapter 3 *Analytical Approaches for assessing Ecosystem Condition and Human Well-Being* in “The Conditions and Trends Assessment (CTA)”, and of Chapter 9 *Changes in Ecosystem Services and their Drivers across the Scenarios* in "The Scenarios Assessment (SA)”.

- Jo House is Lead Author of Chapter 4 *Drivers of Change* in “The Conditions and Trends Assessment (CTA)” and Chapter 7 *Drivers of Change* in SA, Coordinating Lead Author of Chapter 14 *Air quality and Climate* in CTA, and Contributing Author to Chapter 17 *Regulation of Natural Hazards* in CTA.
- Harald Bugmann is Lead Author of Chapter 27 *Mountain Systems* in CTA.
- Ben Smith is Contributing Author to Chapter 14 *Air Quality and Climate* in CTA.
- Richard Klein is contributing author to *Responses to Climate Change* in RA.
- Sandra Lavorel is Review Editor of Chapter 3 *Analytical Approaches for Assessing Ecosystems and Human Well-Being* in CTA.
- Other ATEAMers are invited reviewers to one or several chapters of the MA reports (e.g. Dagmar Schröter to chapter 7 *Vulnerable People and Places* in CTA, chapter 9 *Changes in Ecosystem Services and Their Drivers Across Scenarios* in SA and chapter 13 *Nutrient Cycling* in CTA).

2.1.1.4 Book project *Environmental Vulnerability Assessment for Policy and Decision-Making*

A number of ATEAMers have been invited to contribute to a synthesizing book on Environmental Vulnerability Assessment entitled *Environmental Vulnerability Assessment for Policy and Decision-Making* edited by Anthony G. Patt, Anne C. De la Vega-Leinert and Richard J.T. Klein. The chapters are to be submitted in June 2005, planned for publication in 2006 (here we list only the contributions by ATEAMers):

1. Invited contribution to section 1 (The need for vulnerability information among policy-makers and the public): Cramer, W. *Vulnerability Policy and information needs at the regional and national level: European and German vulnerability policies*. In preparation.
2. Introductory chapter to section 2 (Research and assessment of vulnerability): Klein, R.J.T. *The two fundamental questions of impacts and adaptation as central to vulnerability research, the use of scenarios, models and aggregation techniques*. In preparation.
3. Invited contribution to section 2: Schröter, D. *Vulnerability to changes in Ecosystem services*. In preparation.
4. Introductory chapter to section 3 (Meeting the challenges of vulnerability assessment): De la Vega-Leinert, A.C. *The need for transdisciplinary policy-relevant research*. In preparation.
5. Invited conclusion and synthesis by Downing, T. and R. Leemans.

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2.2.6 2004 Oral and poster presentations

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Rounsevell, M.D.A. Past and future agricultural land use change in Europe, COST Workshop on Carbon storage in European in grassland, June 2004, Gent, Belgium. Presentation.

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Schröter D. 2004. Vulnerability assessment – a tool for analysing human and ecological resilience in face of global environmental change. Environmental Science Section (ESS) Kalmar University Symposium, *Climate risk and vulnerability – exploring conditions for ecological and societal adaptation,* June 7-9, 2004, Kalmar, Sweden. Invited presentation.

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Schröter D. and M.J. Metzger 2004. Global change impacts on ecosystem services and the vulnerability of the human-environment system – The European assessment ATEAM. *Workshop on Global*

Change and the Future of Ecosystems in Europe, sponsored by AVEC (EU-Concerted Action *Integrated Assessment of Vulnerable Ecosystems under Global Change*), EEA (*The European Environment Agency*) and MA (*The Millennium Ecosystem Assessment*), June 10-11, 2004, European Environment Agency, Copenhagen, Denmark. Invited presentation.

Schröter D. and W. Cramer 2004. Environmental impacts of global change. British Ecological Society/European Ecological Federation Annual Symposium, *Ecology without frontiers: Environmental challenges across Europe*, Exeter University, April 5-7 2004, Exeter, UK. Invited presentation.

Schröter, D. 2004. Global change vulnerability – assessing the European human-environment system. Twentieth sessions of the subsidiary bodies (SB 20), United Nations Framework Convention on Climate Change (UNFCCC), *Workshop on Scientific, Technical and Socio-Economic Aspects of Impacts of, Vulnerability and Adaptation to Climate Change*, June 16-25, Hotel Maritim, Bonn, Germany. http://unfccc.int/sessions/workshop/180604/present.html. Invited presentation.

Schröter, D. 2004. Impacts of and vulnerability to climate change in Europe. *Second International Conference on Climate Impacts Assessment (SICCIA)*, joint event of the NOAA Office of Global Programs, the Climate Impacts Group (University of Washington), and the US National Science Foundation, June 28-July 2, Grainau, Germany. Invited presentation.

Schröter, D. et al. 2004. ATEAM's main conclusions on sectoral impacts under plausible multi-scenarios of global change. *Third ATEAM stakeholder dialogue: Vulnerability of European sectors to global changes*. May 3-4, 2004, Potsdam, Germany. Presentation.

Smith, P. 2004. Agricultural soil carbon sequestration. Climate Change. *Science, Impacts and Policy Responses*. April, 2004, Imperial College London, UK. Invited presentation.

Smith, P. 2004. Greenhouse gas budgets of European croplands. *CarboEurope IP kickoff meeting*, Jan 19-22, 2004, Spoletto, Italy. Invited presentation.

Smith, P. 2004. Interactions between Biodiversity, Biogeochemistry and Human Impacts. Research Priorities for Terrestrial Ecosystem Modelling over the next decade. Invited presentation at symposium on "Perspectives in Earth System Science: human interactions, biodiversity and biogeochemistry", Jena, Germany, 11 May 2004

Smith, P. 2004. Soils and the carbon cycle: global and UK perspectives, *CTCD UK Carbon Meeting*, Jan 6-8 2004, Sheffield, UK. Invited presentation.

Thonicke, K. 2004. Fire ecology of the boreal forests. *Annual Meeting of the FP5 TCOS-Siberia project*, Feb 23-25, 2004, Jena, Germany.

Zaehle S., A. Bondeau, P. Smith, S. Sitch, D. Schröter, M. Erhard and W. Cramer 2004. Europe's terrestrial carbon sink may last until 2050 and then decline. *European Geosciences Union, 1st General Assembly,* April 25 – 30, 2004, Nice, France. Presentation.

Zaehle S., A. Bondeau, P. Smith, S. Sitch, D. Schröter, M. Erhard and W. Cramer 2004. Europe's terrestrial carbon sink may last until 2050 and then decline. European Geosciences Union (EGU), 1st General Assembly, April 25 - 30 2004, Nice, France. Presentation.

2.2.7 2003 Oral and poster presentations

Araújo, M.B., Hannah, L., Thuiller, W. 2003. Securing species in protected areas in a climate change context. In V World Parks Congress, Workshop Stream VII *Building a Comprehensive Protected Area System*, IUCN, Sept 8-17, 2003, Durban, South Africa. Presentation.

Bondeau A., P. Smith, S. Zaehle, B. Schröder, B. Smith, D. Gerten, S. Schaphoff, 2003. Accounting for agriculture in modelling the global terrestrial carbon cycle. *First Land Open Science Conference of the LAND project,* Dec 2 -5 2003, Morelia, Mexico. Poster presentation.

Bondeau, A., P. Smith, S. Schaphoff, S. Zaehle, B. Smith, S. Sitch, D. Gerten, B. Schröder, W. Lucht, W. Cramer 2003. Accounting for agriculture in modelling the global terrestrial carbon cycle. *European Geophysical Society (EGS) – American Geophysical Union (AGU) – European Union of Geosciences (EUG) Joint Assembly*, April 6 – 11, 2003, Nice, France. Poster presentation.

Bugmann, H. 2003. Mountain ecosystem goods and services . *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Carpenter, S., H. Gitay, R. Leemans, B. Scholes, and B. Watson. 2003. What is an assessment and what it is not? *Millennium Ecosystem Assessment (MA) Combined Working Group Meeting of Coordinating Lead Authors*, Oct 10-17, 2003, Prague, Czech Republic. Invited lecture.

Ewert, F., I. Reginster, M. Rounsevell, R. Leemans, and E. Kamphorst. 2003. The development of spatially explicit and alternative scenarios of future land use in Europe. *CarboEurope Greenhouse Gas Workshop*, Sept 3-5, 2003, Clermont Ferand, France. Invited lecture.

Cramer, W. 2003. Assessing uncertainty in biospheric carbon storage. *Massachusetts Institute of Technology (MIT) Global Change Forum XXI*, Oct 9, 2003, Boston, MA, USA. Invited presentation.

Cramer, W. 2003. Die Rolle der Primärwälder im globalen Klimageschehen. *Freiburger Regenwald-Tag*, Oct 28, 2003, Freiburg im Breisgau, Germany. Invited presentation.

Cramer, W. 2003. Ecosystem vulnerability and climate change. COP 9 Side event *European greenhouse gas budgets of the biosphere*, Dec 10, 2003, Milano, Italy. Invited presentation.

Cramer, W. 2003. Folgen der Klimaänderung für die Bundesländer. *Hessische Landesanstalt für Umwelt und Geologie, 2. Hessischer Klimaschutzworkshop,* May 13, 2003, Wiesbaden, Germany. Invited presentation.

Cramer, W. 2003. Landnutzungsänderungen und ihr Einfluss auf das Klima. *DECHEMA -- Gesellschaft für Chemische Technik und Biotechnologie e.V.,* March 6, 2003, Frankfurt am Main. Invited presentation.

Cramer, W. 2003. Landnutzungsänderungen und ihr Einfluss auf das Klima. *Institut für Meteorologie und Klimaforschung, Atmosphaerische Umweltforschung (IMK-IFU),* June 11, 2003, Garmisch-Partenkirchen, Germany. Invited presentation.

Cramer, W. 2003. Past and future biotic responses to global climate change. *Swiss NCCR Summer School,* August 31, 2003, Grindelwald, Switzerland. Invited presentation.

Cramer, W. 2003. The ATEAM/AVEC concept of assessing vulnerability. *AVEC Drought Workshop*, April 10, 2003, Samos, Greece. Invited presentation.

Cramer, W. 2003. Towards a continental-scale European carbon balance. *CarboEurope Conference,* March 19, 2003, Lisbon, Portugal. Invited presentation.

Cramer, W. 2003. Zur Rolle terrestrischer Ökosysteme als Puffer für Klimaänderungen. *Forum Federal Agricultural Research Center (FAL),* Nov 4, 2003, Braunschweig, Germany. Invited presentation.

De la Vega-Leinert, A.C. 2003. Theory and practice in science- stakeholder dialogue. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Eggers, T., Lehtonen, A., Liski, J., Mäkipää R., Palosuo, T. 2003. Integrated method to calculate forest carbon budgets – inventory-based estimates compared with eddy covariance measurements. *Fifth plenary meeting of COST E21 The role of forest for mitigating greenhouse gas emissions*, Nov 27-29, 2003, Thessaloniki, Greece. Presentation.

Ewert F, Baker R, Porter JR, Gioli B, Miglietta F, Sansford C. 2003. Assessing the risks to Europe from the Quarantine pathogen *Tilletia indica*, the cause of Karnal bunt of wheat. *Agriculture, Climate Change and Economic Consequences - from Description to Mitigation*, Feb 19-21, 2003, Copenhagen, Denmark. Invited lecture.

Ewert F, Rounsevell M, Reginster I, Metzger M, Kamphorst K, Leemans R. 2003. Estimating changes in primary productivity and effects on agricultural land use. *COST 627, Carbon sequestration opportunities in European grassland: Mitigation scenarios at plot, farm and regional scale*. Sept 7-8, 2003, INRA, Clermont-Ferrand, France. Presentation.

Ewert F, The development of spatially explicit and alternative scenarios of future land use in Europe. International workshop CarboEurope-GHG, Synthesis of the European Greenhouse Gas Budget. 4-5 September 2003, INRA, Clermont-Ferrand, France. Presentation.

Ewert F. and Rounsevell, M.D.A. Technology development and climate change as drivers of future agricultural land use. Rural lands, agriculture and climate beyond 2015: Usage and management responses. December 2003, Wageningen University, the Netherlands. Presentation.

Ewert, F., M. Rounsevell, I. Reginster, E. Kamphorst, C. Simota, E. Audsley, C. Giupponi, P. Rosato, J. Abildtrup, and R. Leemans. 2003. Technology as a driver of future agricultural land use change. *Transition in agriculture and future land use patterns*, Dec 1-3, 2003, Wageningen, The Netherlands. Invited lecture.

House, J. 2003. Land Use Scenarios for Europe: Biofuel Potential and Climate Change *The biofuels directive: potential for climate protection*, Biofuels conference, European Climate Forum, Tyndall Centre, UEA, Sept 8-10, 2003. Invited presentation.

Jongman, R.H.G., Bunce, R.G.H., Metzger, M.J., Mücher, C.A. and Howard, D.C. 2003. A statistical Environmental Classification of Europe: objectives and applications. *International Association for Landscape Ecology World Congress*, July 13-17, 2003, Darwin, Australia. Presentation.

Leemans, R. 2003. Concepts in global climate change. PE&RC Day 2003, Nov 20, 2003, Wageningen, The Netherlands. Presentation.

Leemans, R. 2003. De keten van klimaatverandering: simulaties met het IMAGE-2 model. Lecture at Vereniging "de Ronde Tafel", Oct 8, 2003, Bilthoven, The Netherlands. Presentation.

Leemans, R. 2003. Developing scenarios within a global context. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Leemans, R. 2003. Environmental Systems Analysis: continuation and further Integration. SENSE meeting, Dec 11, 2003, Vrije Universiteit, Amsterdam, The Netherlands. Plenary presentation.

Leemans, R. 2003. Global environmental change and Health: integrating knowledge from natural, socio-economic and medical sciences. *Environmental Change and malaria risk: Global and local implications*, Nov12-14, 2003, Wageningen, The Netherlands. Presentation.

Leemans, R. 2003. Integrated assessment: Modelling global change with IMAGE. *Health Scenarios and Climate Change: An Outline for the Future*, July 21-22, 2003, Washington DC, USA. Key Note Lecture

Leemans, R. 2003. Integrating vulnerability indicators from natural and social science. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Leemans, R. 2003. The philosophy and structure of the Millennium Assessment Responses Working Group. *Media Seminar on the Millennium Ecosystem Assessment*,Oct 13-14, 2003, Prague, Czech Republic. Presentation.

Liski, J. 2003. Estimating forest carbon budgets using forest-inventory-based methods. *Fifth plenary* *meeting of COST E21 The role of forest for mitigating greenhouse gas emissions*, Nov 27-29, 2003, Thessaloniki, Greece. Presentation.

Liski, J. 2003. Expected changes in soil carbon as a consequence of climate change. *Methods for the detection of changes in soil carbon stocks under climate change*, Edinburgh, UK, Oct 29 - 31, 2003. Presentation.

Liski, J., Palosuo, T., Eggers, T. & Sievänen, R. 2003. Simple dynamic soil carbon model. *CarboEurope Conference The continental carbon cycle*, March 19-21, 2003, Lisbon, Portugal. Poster presentation.

Metzger, M.J. 2003. Mapping vulnerability across Europe. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Palosuo T., Liski J., Trofymow J.A., Titus B. 2003. Soil carbon model tested using extensive litter decomposition data from Canada. *Fifth plenary meeting of COST E21 The role of forest for mitigating greenhouse gas emissions*, Nov 27-29, 2003, Thessaloniki, Greece. Poster presentation.

Prentice, C. 2003. The European biosphere and global change. Connectivities in the Earth System. 3rd International Geosphere Biosphere Programme (IGBP) Congress, 19-24 June, 2003, Banff, Canada. Presentation.

Reginster, I., M. Rounsevell, E. Kamphorst, E. Audsley, T. Carter, C. Giupponi, S. Kankaanpää, R. Leemans, J. Pluimers, P. Rosato, 2003, Land use change scenarios for Europe. *Framing Land Use Dynamics*, Utrecht International Conference, April 16-18, 2003, Utrecht, The Netherlands. Presentation.

Rounsevell M, Reginster I, Ewert F. 2003. Land use change in Europe: interpreting regional scenarios from global storylines. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Schaeffer, M., B. Eickhout, M. Hoogwijk, R. Leemans, T. Opsteegh, and D. van Vuuren. 2003. The CO_2 and non-CO_2 climate impact of extra-tropical biomass and carbon plantations. Sept 2004, Helsinki, Finland. Poster presentation.

Schröter D. 2003. Climate change impacts and vulnerability. 3rd Meeting of Environmental Policy Departments of EU-Member States' Foreign Ministries *Confidence Building Measures by the EU on International Climate Change*. Deutsches Auswärtiges Amt (German Foreign Ministry), May 15-16, 2003, Berlin, Germany. Invited presentation.

Schröter D., L. Acosta-Michlik, P. Reidsma, M.J. Metzger and R.J.T. Klein 2003. Modelling the vulnerability of eco-social systems to global change: Human adaptive capacity to changes in ecosystem service provision. *Open Meeting of the Human Dimensions of Global Environmental Change Research Community*, Oct 16-18, 2003, Montreal, Canada. Presentation.

Schröter D., L. Brussaard, G. De Deyn, K. Poveda, V.K. Brown, M. Berg, D. Wardle, J. Moore, D.H. Wall 2003. Modelling above- and belowground interactions in a changing world. *Biosphere Interactions in the Earth System - BIS Science Day,* June 5, 2003, Potsdam, Germany. Invited presentation.

Schröter D., M. Metzger, R. Leemans and W. Cramer 2003. ATEAM: Europaweite Kartierung von Vulnerabilität, bezogen auf Ökosystemfunktionen. *Colloquium for the Arid Climate, Adaptation and Cultural Innovation in Africa (ACACIA) special research theme project of the German Science Foundation*, University of Cologne, May 27, 2003, Köln, Germany. Invited presentation.

Schröter D., S. Zaehle, S. Schaphoff, W. Lucht and W. Cramer 2003. Modelling global change effects on vegetation and exploring our vulnerability. *Global Climate Change and Biodiversity Conference*. Tyndall Centre for Climate Change Research, University of East Anglia, April 8-10, 2003, Norwich, UK. Invited presentation.

Schröter, D. 2003. Introduction to the vulnerability concept -- Global Environmental change and Ecosystem Services. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Schröter, D. and M. Metzger 2003. The concept of vulnerability and a vulnerability assessment in Europe. January 14, 2002, EVA-seminar series, Potsdam, Germany. Invited presentation.

Schröter, D., M. Metzger, S. Zaehle, W. Cramer and the ATEAM consortium, 2003. A European Vulnerability Assessment. *First Land Open Science Conference of the LAND project,* Dec 2 -5 2003, Morelia, Mexico. Poster presentation.

Schröter, D., P.C. De Ruiter and V. Wolters 2003. Mineralisation in the decomposer food webs of a European forest transect: The impact of nitrogen deposition. *Food Web Symposium 2003*, Nov 13-16, 2003, Schloss Rauischholzhausen, Gießen, Germany. Invited presentation.

Sitch, S. 2003. Carbon cycle and global vulnerability. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC, EVK2-2001-000874)*. Sept 14-27, 2003, Peyresq, France. Invited presentation.

Sitch, S., Brovkin, V., and von Bloh, W. 2003. Simulation of historical atmospheric CO_2 dynamics using the coupled climate- carbon model, CLIMBER2-LPJ. *European Geophysical Society (EGS) – American Geophysical Union (AGU) – European Union of Geosciences (EUG) Joint Assembly*, April 6 – 11, 2003, Nice, France. Poster presentation.

Smith, P. 2003. Agriculture and climate change. *Land- und Forstwirtschaft als Senken für atmosphärischen Kohlenstoff in Deutschland: Prozesse, Datenbedarf und Handlungsoptionen*, Nov 2003, Braunschweig, Germany. Invited Presentation.

Smith, P. 2003. Carbon sequestration in EU-15: potential and verification. *CArbon Sequestration potential in different Belgian Terrestrial ECosystems: quantification and strategic exploration*, Oct 2003, University of Gent, Belgium. Invited Presentation.

Smith, P. 2003. European agriculture and carbon: the big unknown. COP 9 Side event *European greenhouse gas budgets of the biosphere*, Dec 10, 2003, Milano, Italy. Invited presentation.

Smith, P. 2003. Greenhouse gas fluxes in European cropland. CarboEurope GHG meeting on Cropland and Grassland GHG fluxes, Clermont-Ferrand, France, 4-6 September 2003. Presentation.

Smith, P. 2003. Impacts of climate change on agriculture. *EU International Summer School 2003: Integrated Assessment of Vulnerable Ecosystems under Global Change (AVEC)*. Sept. 22, 2003, Peyresq, France. Invited presentation

Smith, P. 2003. Landscape-scale modelling of European grassland soils. COST Action 627, Carbon Sequestration in European Grasslands, Sept 7, 2003, Clermont-Ferrand, France. Invited presentation

Smith, P. 2003. Methods for detecting soil carbon change: the experience of SOMNET. *ESF Workshop Methods for the detection of changes in soil carbon stocks under climate change*, Oct 29-31, 2003, Edinburgh, Scotland. Invited presentation.

Smith, P. 2003. Sustainable soil management to help mitigate climate change: opportunities and limitations. *The Science of Sustainable Agriculture*, Oct 17 2003, University of California, Davis, CA, USA. Invited Presentation.

Thonicke, K. 2003. Fire and Vegetation Dynamics in a Dynamic Global Vegetation Model. *MPI-Met. Seminar Series*, Oct. 27, 2003, Hamburg, Germany. Invited Presentation.

Thonicke, K. 2003. Fire and Vegetation Dynamics in a Dynamic Global Vegetation Model. *2nd annual meeting of the FP5 RETRO project*, Nov. 20-21, 2003, Lisbon, Portugal. Invited Presentation.

Thonicke, K., S. Sitch, W. Cramer (2003). Simulating changes in fire and ecosystem productivity under climate change conditions. *European Geophysical Society (EGS) – American Geophysical Union (AGU) – European Union of Geosciences (EUG) Joint Assembly*, April 6 – 11, 2003, Nice, France. Poster presentation.

Zierl, B. and H. Bugmann 2003. Sensitivity of alpine watersheds to global change. European Geophysical Society, Nizza, France, April 7th - 11th. Presentation.

Zierl, B. and H. Bugmann 2003. Sensitivity of Swiss mountain water sheds to global change. Mountain Hydrology Workshop, Einsiedeln, Switzerland. April 2nd - 4th, 2003. Presentation.

2.2.8 2002 Oral and poster presentations

Araújo, M. 2002. Dynamics of extinction and the selection of nature reserves. Society for Conservation Biology Annual Meeting, June 2002, University of Kent, Cantebury, UK. Presentation.

Araújo, M.B. 2001. Mapping biodiversity with WORLDMAP. In International Workshop on Subterranean Biodiversity. Laboratoire Souterrain du CNRS, Moulis, France. Presentation.

Araújo, M.B., Williams, P.H. & Fuller, R.J. 2002. Dynamics of extinction and the selection of nature reserves. In Annual Meeting in Conservation Biology. SCB, University of Kent, Canterbury, UK. Presentation.

Cramer, W. 2002. "Assessing global change impacts on ecosystem services: interfacing 'hard science' and stakeholders". World Congress on Natural Resource Modelling. June 23-26 2002. Lesvos, Greece. Presentation.

Cramer, W. 2002. "Recent Developments of ecological Assessment to environmental change in Europe". CNRS — Programme Environnement, Vie et Sociétés Séminaire Ingénierie écologique, II - Conservation, restauration, évaluation écologique, March 4th 2002, Ecole Normale Supérieure, Paris, France. Presentation.

Cramer, W. 2002. „Die Dynamik der Biosphäre im Erdsystem: Brauchen wir die Ökologie zur Quantifizierung von Risiken für die Menschheit?“. University of Potsdam, Colloquium on Global Ecology. April 15th 2002,Potsdam, Germany. Presentation.

Cramer, W. and ATEAM members 2002. Quantitative assessment of ecosystem service vulnerability to climate change. ICTP Conference on Detection and Modeling of Regional Climate Change. The Abdus Salam International Centre for Theoretical Physics. October 1-2 2002, Trieste, Italy. Presentation.

Jongman, R.H.G., R.H.G. Bunce, B. Elbersen, M.J. Metzger, C.A. Mücher and M. Perez-Soba Integration between remote sensing, environmental stratification and field sampling in Europe. “CEMAGREF-EPA workshop”. Montpellier, 28-30 October 2002. Presentation.

Klein, R.J.T. and D. Schröter 2002. Vulnerability: Analysis, Modelling and Policy. The Potsdam Institute for Climate Impact Research ToPIK Days, December 17-18, 2002. Presentation.

Lavorel, S. 2002. Vulnerability of European biodiversity to global change. Seminar at Australian National University July 2002. Presentation

Lavorel, S. 2002. Vulnerability of European biodiversity to global change. Seminar at the ETH Zürich, May 2002. Presentation.

Leemans, R. 2002. Complexe dynamics, hierarchical scales and biodiversity. Lecture at the Studium Generale course “Comlex dynamics in and between social and ecosystems” Wageningen University, Wageningen, 4 November 2002. Presentation.

Leemans, R. 2002. Comprehensive scenarios of global change. Seminar International Institute of Advanced Studies, UNU. 22 November 2002. Tokyo, Japan. Presentation.

Leemans, R. 2002. Effects of global change on ecosystem goods and services. Lecture Sense Course “Human Dimensions of Global Environmental Change”. Wageningen, 2-6 December 2002. Presentation.

Leemans, R. 2002. Projected increase in population and wealth and the consequences for food demand. Keynote lecture at the conference “Agriculture, food production and market price: Do we have a sustainable food chain? SCI & British Grassland Society, London 5 November 2002. Presentation.

Leemans, R. 2002. Scenario development and application: An introduction on the ATEAM land-use scenarios. Lecture at the 2nd ATEAM stakeholder meeting. 16-17 September 2002, Potsdam, Germany. Presentation.

Leemans, R. 2002. Space-time patterns of human influences on the C cycle. 2nd meeting of the Scientific Steering Committee for the Global Carbon Project. 18-21 November 2002. Tsukuba, Japan. Presentation.

Leemans, R. 2002. The ecosystem approach to strengthen capacity to manage ecosystems sustainably for human well-being. Key-note lecture Global Biodiversity Forum Meeting “Using the ecosystem approach in forest management”, 5-7 April 2002. The Hague. Presentation.

Leemans, R. 2002. The relations between the global change programmes and the Millennium Ecosystem Assessment. IGBP-Workshop “Developing the research programme of the new IGBP land project”, Den Dolder, 10-13 October 2002. Presentation.

Leemans, R. 2002. What constitutes a “Dangerous” Level of Climate Change? A synthesis of vulnerability. R. Leemans Key-note lecture symposium “Climate change in Portugal. Scenarios, impacts and adaptation measures (SIAM project)”, Lisbon, Portugal, 21 June 2002. Presentation.

Leemans, R. 2002.Methodology of integrated assessment modelling and process. Invited lecture Blueprint Workshop Tyndall Centre, Southampton February 27-28, 2002 Presentation.

Leemans, R. and B. Eickhout 2002. Introduction to integrated assessment modelling. Lecture course “Climate change and greenhouse effect” of the Environmental Sciences Study Program, Wageningen, 4 April 2002. Presentation.

Mücher, C.A., G.J. Roerink, and M.J. Metzger 2002. Study of vegetation dynamics in relation to climate parameters. “European Phenology Network workshop: Use of Earth observation data for phenological monitoring” Joint Research Centre, Italy, 12-13 December, 2002. Presentation.

Schröter D. and W. Cramer 2002. Assessing vulnerability in Europe: the ATEAM project. Meeting at NOAA: Modelling vulnerability and adaptation. October 3, 2002, Washington DC, USA. Presentation.

Schröter D. and W. Cramer 2002. Assessing vulnerability in Europe: a stakeholder guided approach based on a framework of ecosystem models. Vulnerability Methods and Models Workshop, October 16-18, 2002, John F. Kennedy School of Government, Harvard University, Boston, USA. Presentation.

Schröter, D., M. Metzger, R. Leemans and W. Cramer 2002. The concept of vulnerability and a vulnerability assessment in Europe. Workshop of the EU project INTEGRATION. November 25-26, 2002, Potsdam, Germany. Presentation.

Thuiller, W. 2002 Modélisation écologique et biodiversité : une approche pour prévoir les effets des changements globaux. Ecole Thématique CNRS : Quelles interactions entre sciences de la vie et sciences humaines October 2002. Presentation.

Thuiller, W. and G. Midgley 2002. Evaluating species distribution models: methodologies and conservation implications of prevalence and probability thresholds. November 2002 workshop on species bioclimatic modelling. Sponsored by the Centre for Applied Biodiversity Research (Conservation International, Washington DC). Location: 'Centre d'Ecologie Fonctionnelle et Evolutive, CNRS Montpellier'. Presentation.

Zierl, B. 2002. Global Change Impact on Mountain Ecosystem Services. "Seminarreihe Pflanzenwissenschaften", Universität Bern, Switzerland, 3.6.2002. Presentation.

Zierl, B. 2002. Global Change Impact on Mountain Ecosystem Services. "International Symposium: Ecological and Economic Benefits of Mountain Forests", Innsbruck, Austria, 16.-18.9.2002. Presentation.

Zierl, B. 2002. Ökosystem-Dienstleistungen in Europäischen Gebirgen und globale Umweltveränderungen. "Gebirgswaldökologie-Seminar", ETH Zürich, Switzerland, 31.1.2002. Oral Pesentation.

Zierl, B. 2002. Sensitivity of terrestrial carbon storage in mountain watersheds to global change. "Wengen Workshops on Global Change Research: Quantifying Terrestrial Carbon Sinks: Science, Technology and Policy", Wengen, Switzerland, 25.-27.9.2002. Presentation.

Zierl, B. 2002. Vulnerability Assessment of Mountain Ecosystem Services to Global Change. "Swiss Global Change Day", Bern, Switzerland, 4.4.2002. Poster Presentation.

2.2.9 2001 Oral and poster presentations

Cramer, W. 2001. Assessing the vulnerability of terrestrial ecosystems to global change. “Research and Assessment Systems for Sustainability Summer Study”, Airlie House, Warrenton, Virginia, USA, May 29th-June 1st, 2001. Presentation.

Kamphorst, E. and M. Rounsevell 2001. Assessing Climate Change Effects on Land use and Ecosystems: from Regional Analysis to the European Scale. Open Science Conference: Challenges of a changing world, 10-13 July, 2001, Amsterdam, The Netherlands. Poster.

Schröter, D. and W. Cramer 2001. The ATEAM-Project: Ecosystem Modelling and Vulnerability Assessment. Workshop: Global Change and water Resources in the Mediterranean Region, Toledo, Spain, 2-8 December, 2001. Presentation.

Schröter, D. and W. Cramer, 2001. Assessing vulnerability of European ecosystem services, Workshop: Methods and Models of Vulnerability Research, Analysis and Assessment, 28–30 September 2001, Potsdam, Germany. Presentation.

Sitch, S., A. Bondeau, W. Cramer, W. Lucht, I. C. Prentice, B. Smith, M. Sykes, K. Thonicke, S. Venevsky 2001. Applications of LPJ-DGVM and GUESS terrestrial biosphere models to global change issues. Open Science Conference: Challenges of a changing world, 10-13 July, 2001, Amsterdam, The Netherlands. Poster.

Annex 3 – Figures and tables of results

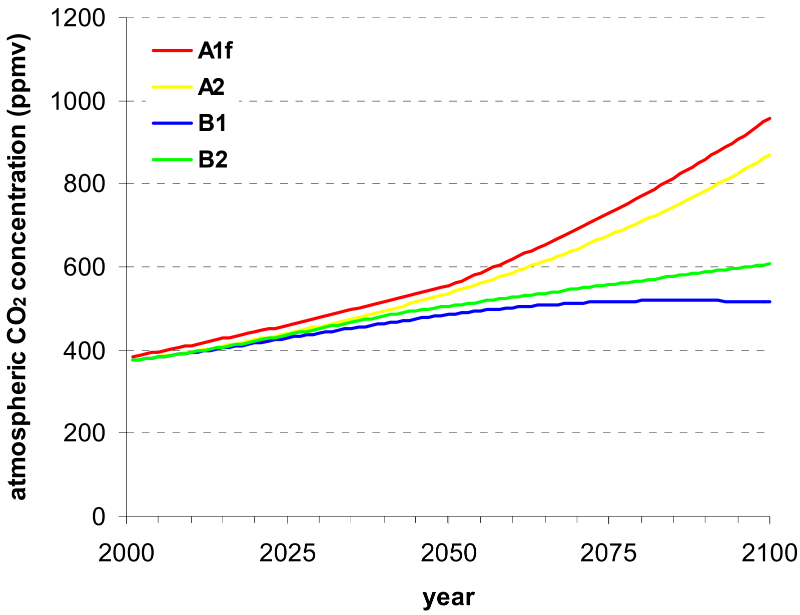
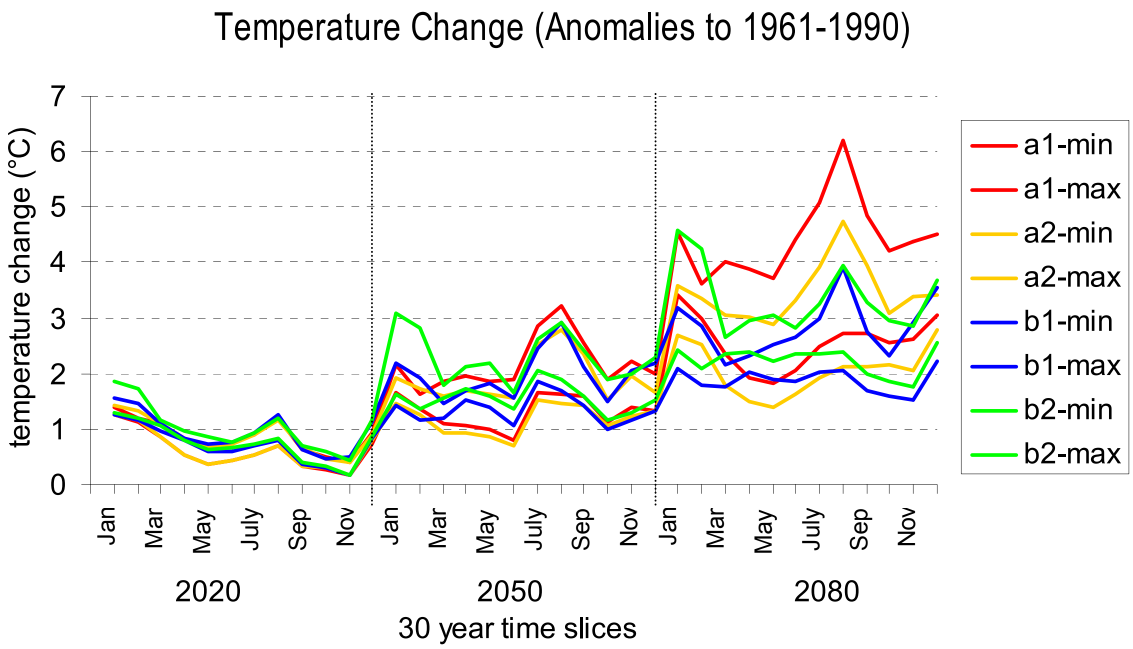


Figure 2. Atmospheric carbon dioxide concentration (ppmv) in the different emission scenarios over time. Please note that the climate models were forced with these atmospheric CO_2-concentrations plus CO_2-equivalents accounting for the other greenhouse gases (such as N_2O, CH_4 etc).



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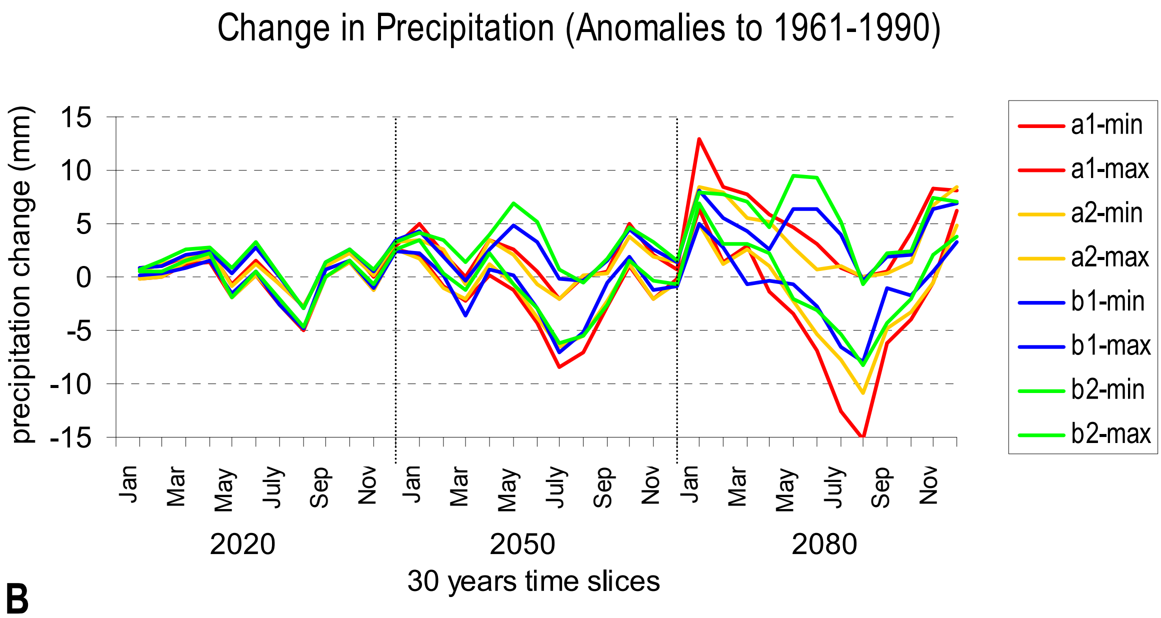

B

Figure 3 Change in monthly temperature (A) and precipitation (B) over the year in the time slices compared to mean monthly values of the baseline 1990 (time slices are 30 year averages: time slice 1990 is an average over period 1961 – 1990, time slices 2020 is an average over period 1991 - 2020, time slice 2050 over period 2021 – 2050, and time slice 2080 over period 2051 – 2080). The curves represent the range of results in four climate models for each of the 4 SRES emission scenarios (A1f red, A2 yellow, B1 blue , B2 green). The range is depicted by the minimum and maximum value from projections with the four general circulation models per SRES scenario (Data from Mitchell et al. 2004).

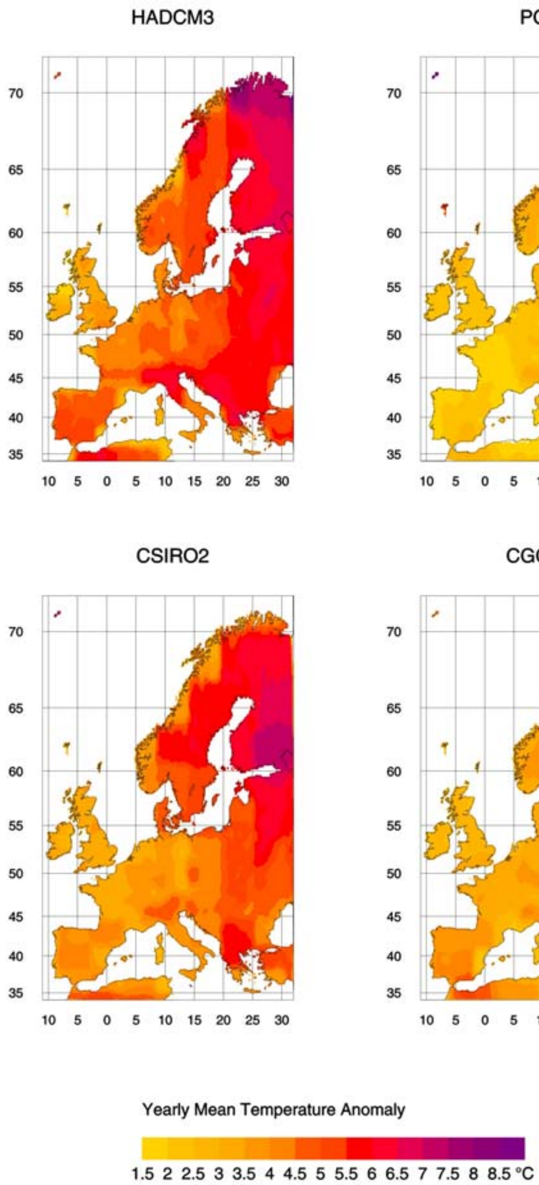

Figure 4. Annual average temperature anomaly for the A2 scenario (2091-2100 compared to 1961-1990). The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

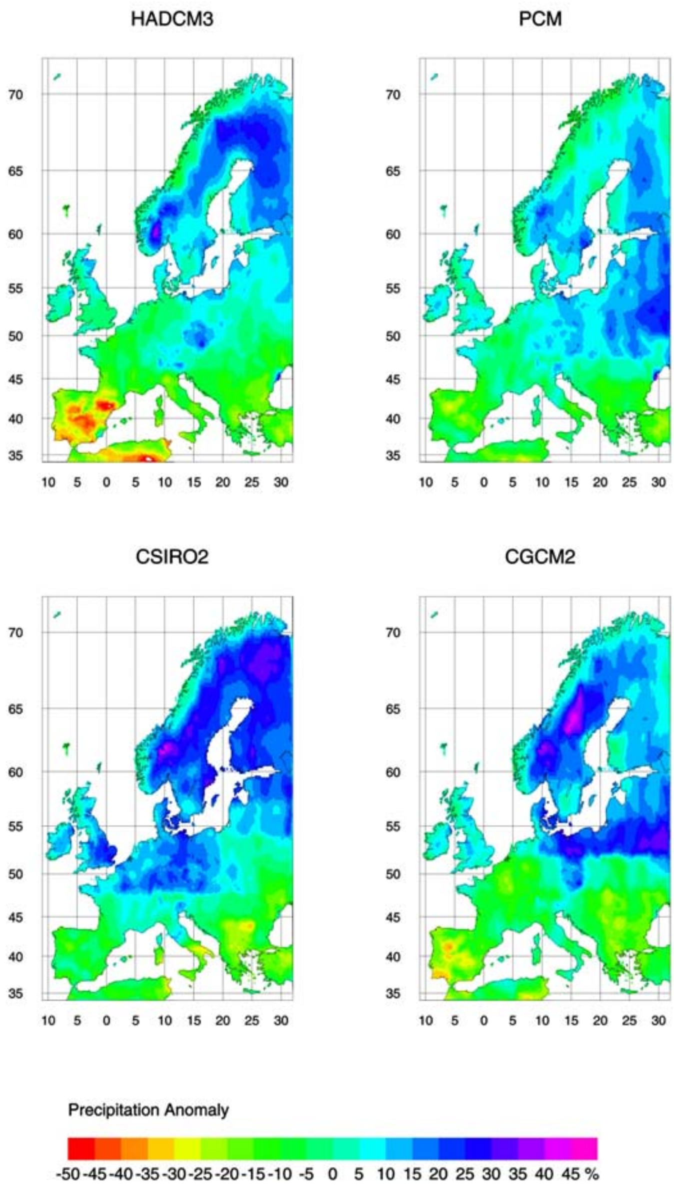

Figure 5. Annual average precipitation anomaly for the A2 scenario (2091-2100 compared to 1961-1990). The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

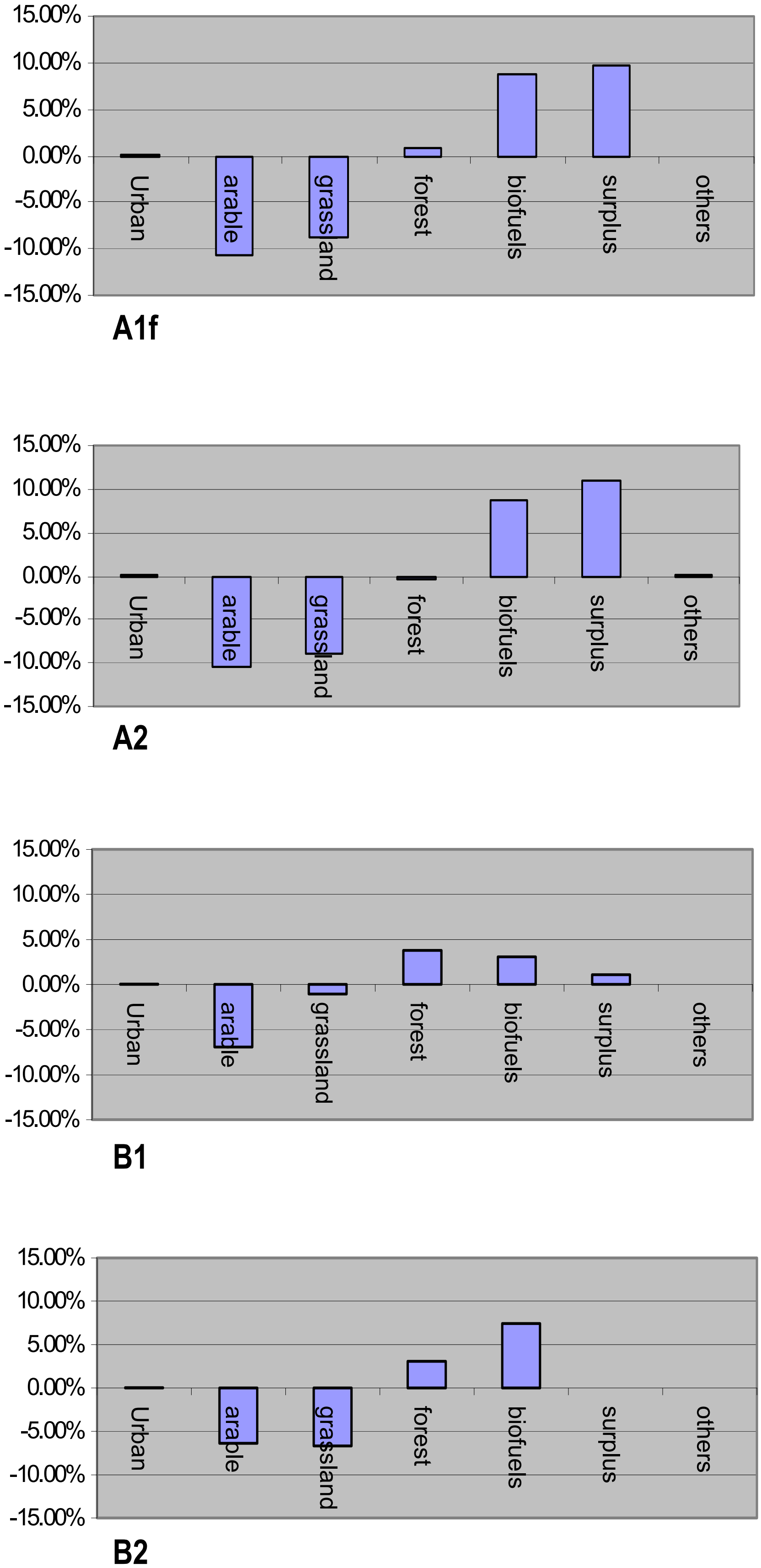

Figure 6. Aggregated land use change trends for Europe: emission scenario A1f, A2, B1 and B2, year 2080, climate model HADCM3. Surplus land is land of unknown use that is theoretically leftover after the

demand for all other uses has been satisfied.

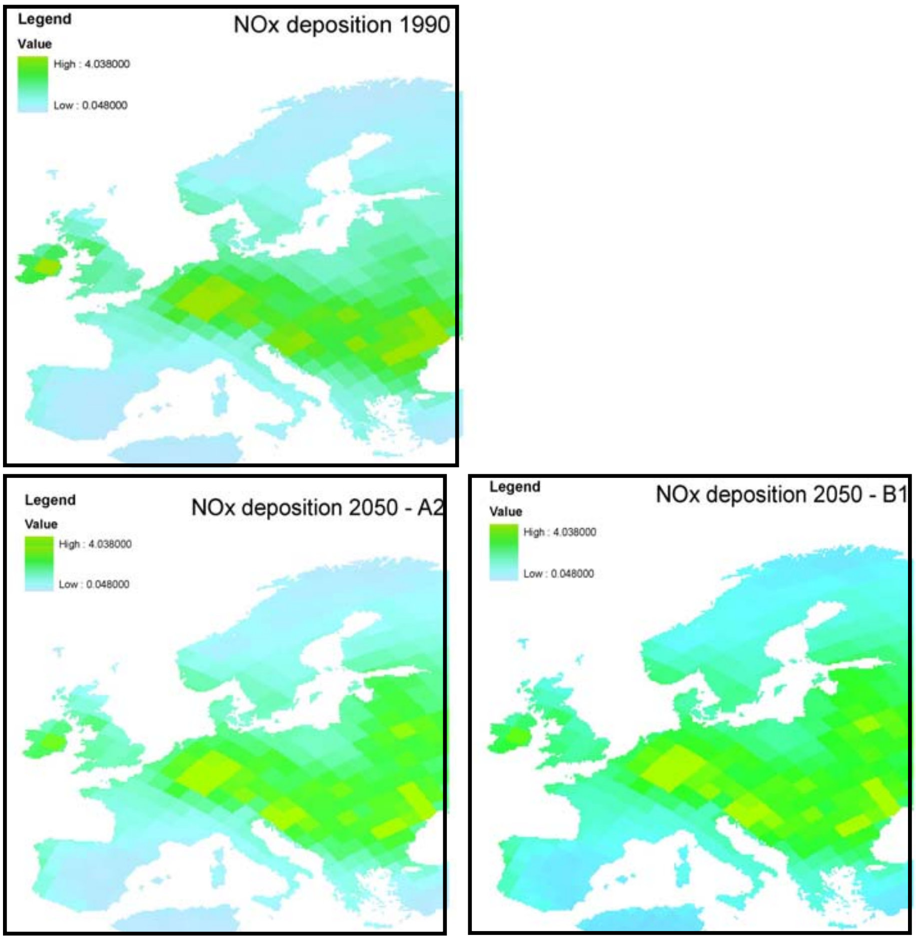

Figure 7. Nitrous oxide deposition, baseline (1990) and two scenarios (A2, B1) for 2050.

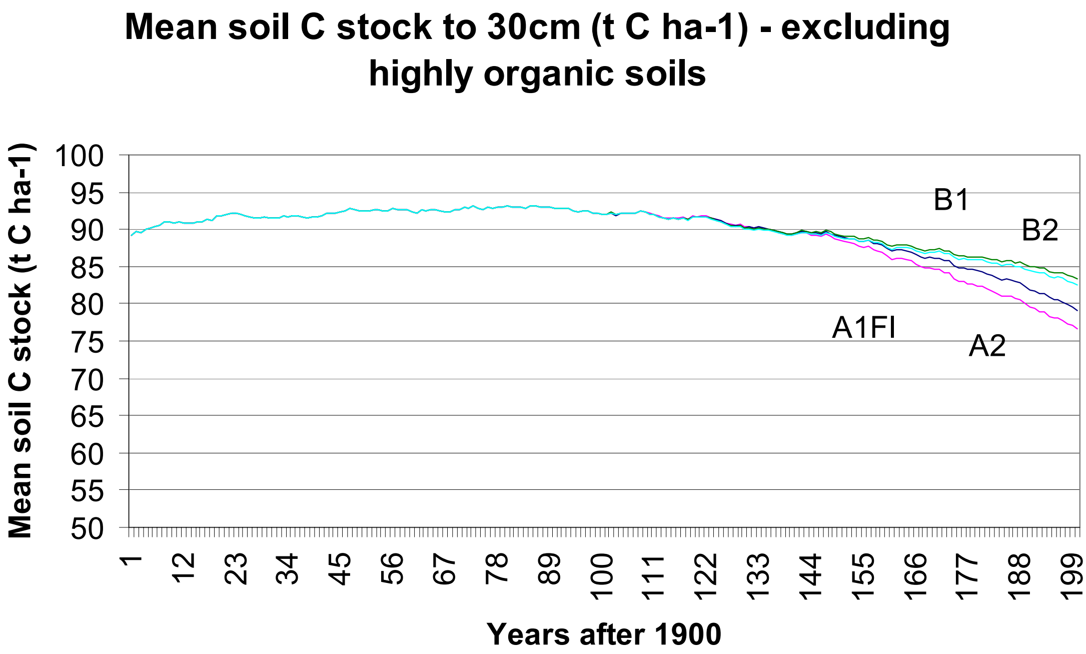

Figure 8. Mean soil organic carbon stock in crop- and grasslands during 21st C from HadCM3 under 4 different climate scenarios.

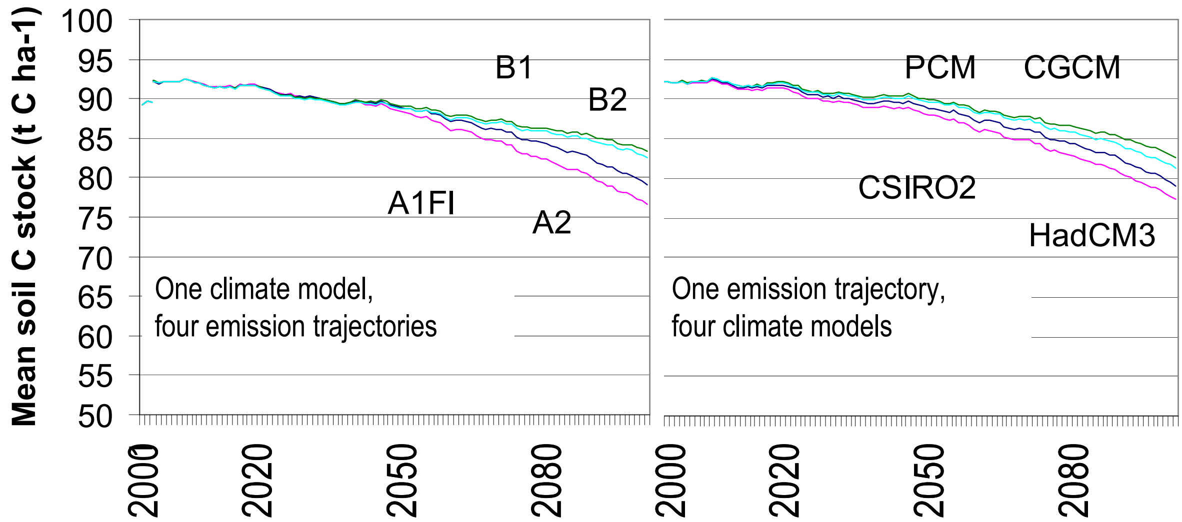

Figure 9. Comparison of the variation in mean soil organic carbon stocks in crop- and grasslands (t C ha^{-1} to 30 cm depth, excluding highly organic soils) between different emission scenarios (A1f, A2, B1, B2) with the variation between different GCMs (PCM, CGCM2, CSIRO2, HadCM3).

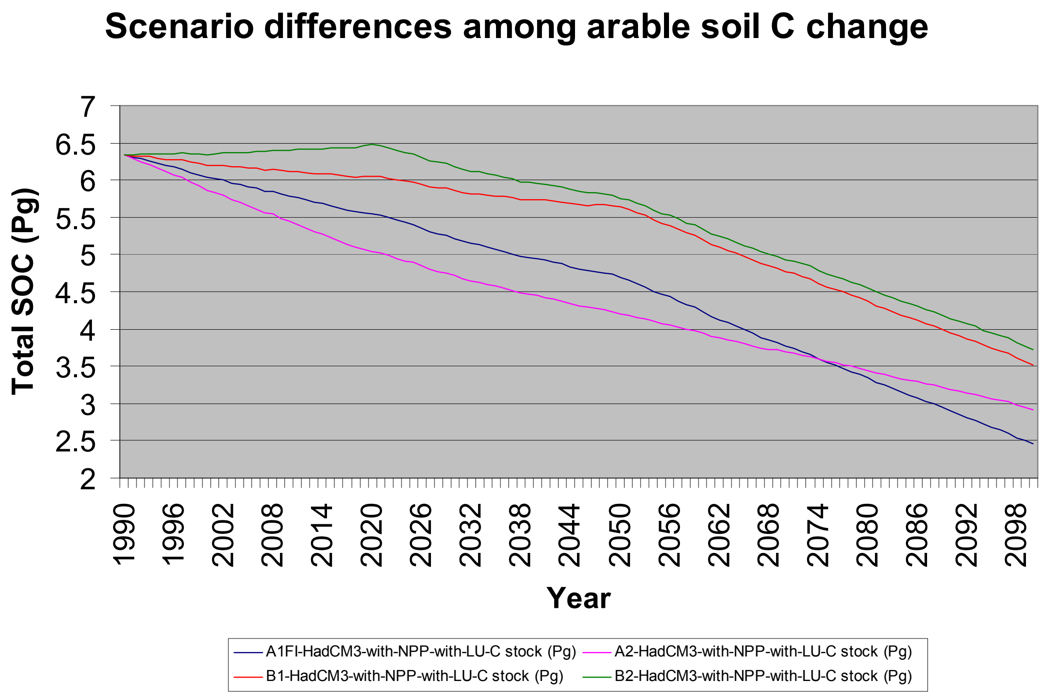

Figure 10. Example of the influence of land-use change. Land use causes the scenarios to diverge further than does climate alone. SOC = soil organic carbon content.

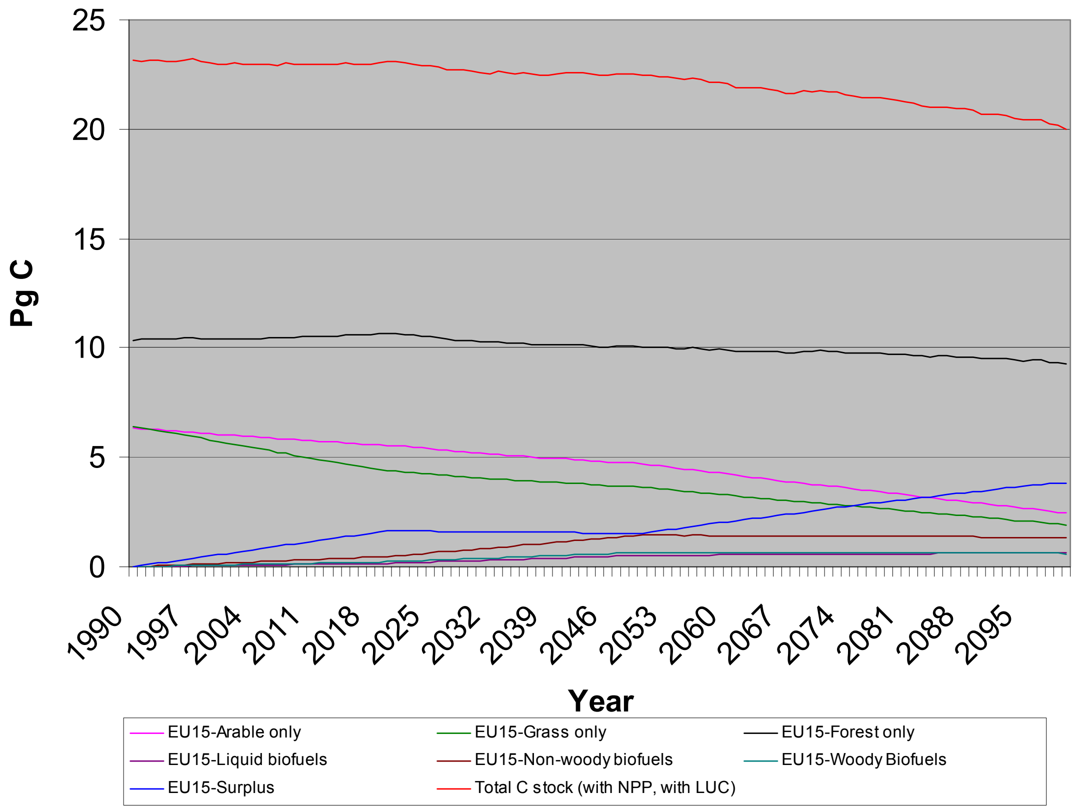

Figure 11. Components of total soil carbon stock change 1990-2100. Total carbon stock (in red) declines, but not as quickly as would be the case if low soil carbon land-uses (e.g. croplands) were not converted to higher soil carbon land uses (e.g. forest, woody bioenergy crops, non-woody, perennial

bioenergy crops).

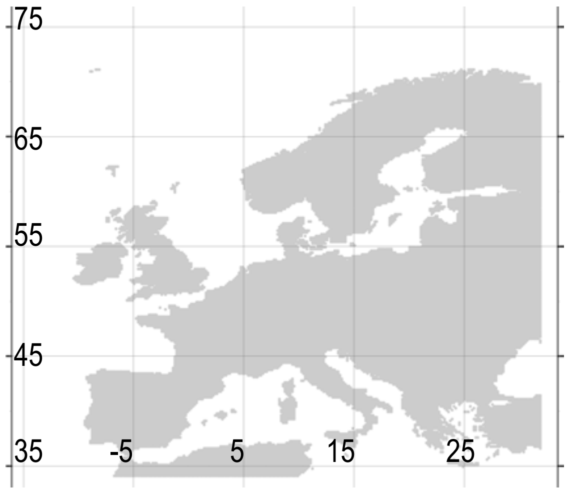

Figure 12. Map of Europe, showing latitude bands used in Table 6.

Table 7. Percentage of total land area in different latitudes of Europe potentially suitable, in terms of climate, for growing biomass energy crops in 1990. Change in potential area due to climate change in 2020s, 2050s and 2080s. Climate scenario A2-HadCM3. Increase(↑) or decrease (↓) in % land area: ↑ or ↓ = 3-10% of land area; ↑↑or ↓↓ = 11-20%; ↑↑↑ or ↓↓↓ =21-30%; ↑↑↑↑ or ↓↓↓↓ = 31-40% etc. See Figure 12 for an illustration of the latitudinal bands.

Latitude (degrees)	**35-44**				**45-54**				**55-64**				**65-71**			
Timeslice	1990	2020	2050	2080	1990	2020	2050	2080	1990	2020	2050	2080	1990	2020	2050	2080
Potential biomass energy crop	% area	Change in area relative to 1990			% area	Change in area relative to 1990			% area	Change in area relative to 1990			% area	Change in area relative to 1990		
Sunflower	66	↑		↓	55	↓	↑↑	↑↑	0			↑	0			
Safflower	16		↑	↑↑	0			↑	0				0			
Rape	63				89				71			↑	0			↑↑↑
Linseed	51	↑	↓↓	↓↓↓	89			↓↓	84	↓			11	↑↑		↑↑↑↑↑
Field Mustard	9		↓		48	↑	↓↓	↓↓↓	19	↑↑↑↑	↑	↑	0			↑
Castor	44	↓	↑		11	↓	↑	↑↑↑	0				0			
Olives	71	↑↑	↑		9	↑↑↑↑↑↑	↑	↑↑	0		↑	↑↑	0			
Soybean	75	↓	↓		25	↑↑↑↑↑		↑	0	↑↑	↑↑	↑	0			
Groundnut	27		↑	↑↑	3		↑	↑	0				0			
Barley	72		↓	↓↓↓	92			↓	85	↑			19	↑↑↑↑	↑↑	↑↑↑
Wheat	58		↓↓↓	↓↓↓	91			↓↓	71	↑↑		↑	0	↑↑↑	↑↑	↑↑↑↑
Oats	4				66	↓	↓↓↓	↓↓	69		↓	↓↓	0			↑↑
Rye	10	↓	↓		77	↓	↓↓↓	↓↓↓	72	↑		↓	0			↑↑↑
Potato	5		↓		61	↓	↓↓↓	↓↓	73	↑		↓↓	0	↑		↑↑↑↑↑
Sugarbeet	62		↓	↓↓↓	76	↑			69	↑		↑	0	↑		↑↑↑↑↑
Sugarcane	6	↓			0				0				0			
Maize whole	70	↓	↓		87	↑			77	↑	↑		12	↑↑↑	↑↑↑	↑↑↑
Hemp	19	↓	↓	↓	53	↑↑	↓	↓↓↓	12	↑↑↑↑↑	↑↑	↑	0			↑↑
Jerusalem Artichoke	3				46	↓	↓↓↓	↓	48			↓	12	↑↑↑↑	↑	↑↑↑
Cardoon	12	↑↑			4	↑	↑	↑	0				0			
Kenaf	33	↑	↓	↓↓	29	↑	↑↑	↑	0			↑	0			
Prickly Pear	11			↑	0				0				0			
Sorghum	25	↑↑↑	↑	↓	22	↓	↑	↑↑	0				0			
Reed Canary Grass	66	↓↓	↓		58	↑↑			33	↑↑↑↑	↑		18	↑	↑	↑↑↑
Miscanthus	56	↓↓	↓		54	↑↑			7	↑↑	↑	↑↑	0			
SRC	4				42	↑	↓↓	↓↓↓	28	↑↑↑↑	↑	↓	7	↑	↑	↑↑
Eucalyptus	92	↓	↓	↓↓↓	89	↑			39	↑↑	↑	↑↑	0			

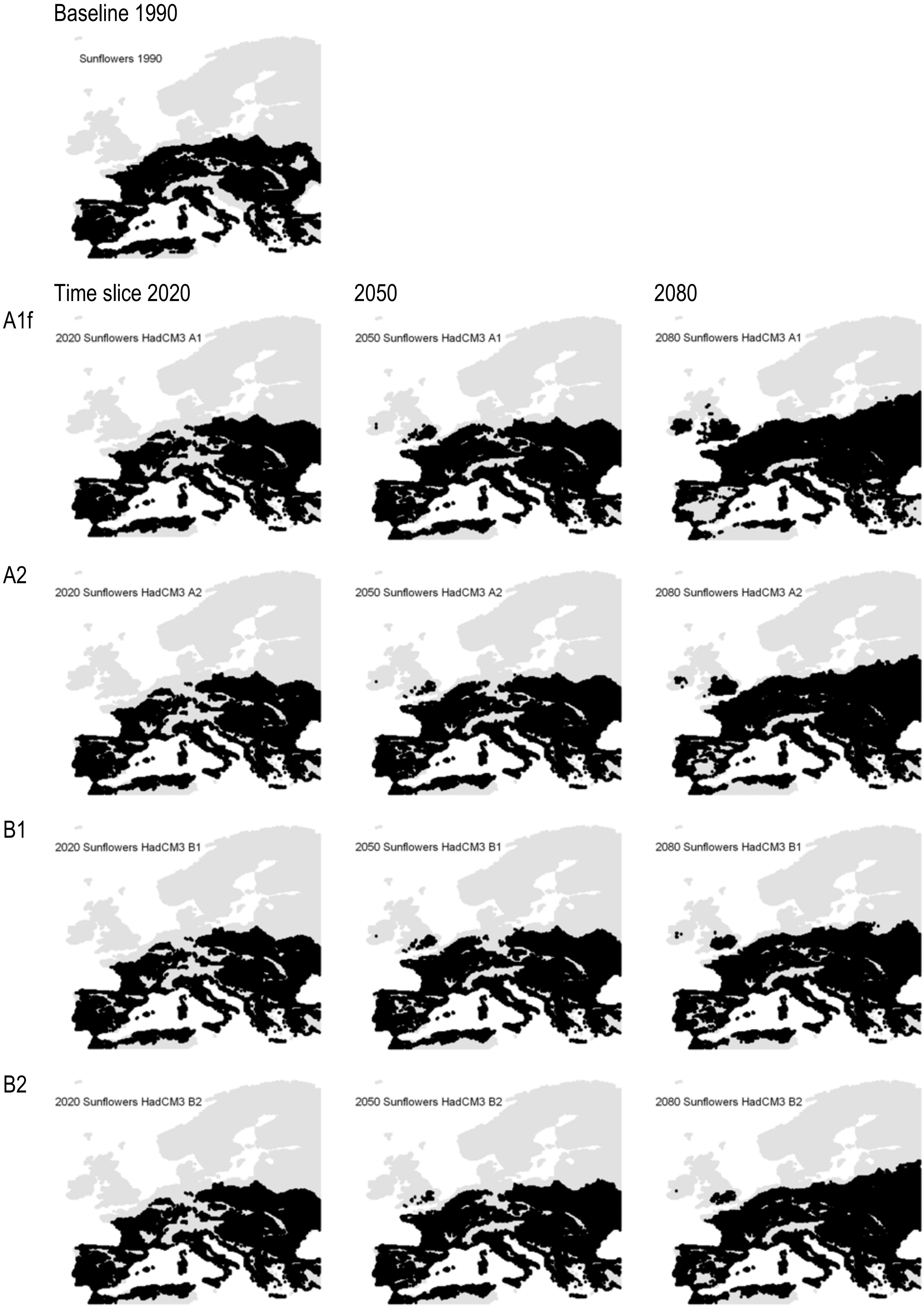

Figure 13. Modelled potential distribution of sunflower in Europe, using HadCM3 climate change model, and A1, A2, B1, and B2 scenarios for the time slices 2020, 2050, and 2080. The baseline (1990) is shown for comparison.

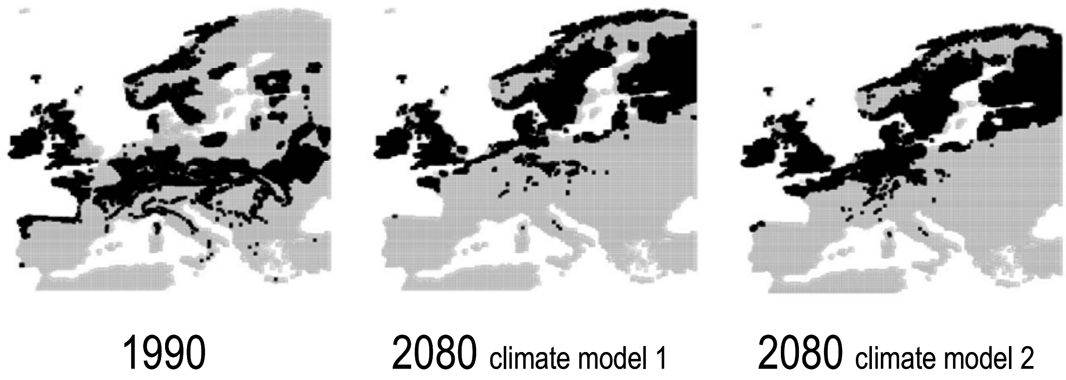

Figure 14. Climate suitability maps for short rotation coppice (SRC), using baseline (1990) climate data and simulated 2080 climate produced by two different climate models (climate model 1 = HadCM3, climate model 2 = CSIRO2), with the A2 emission scenario.

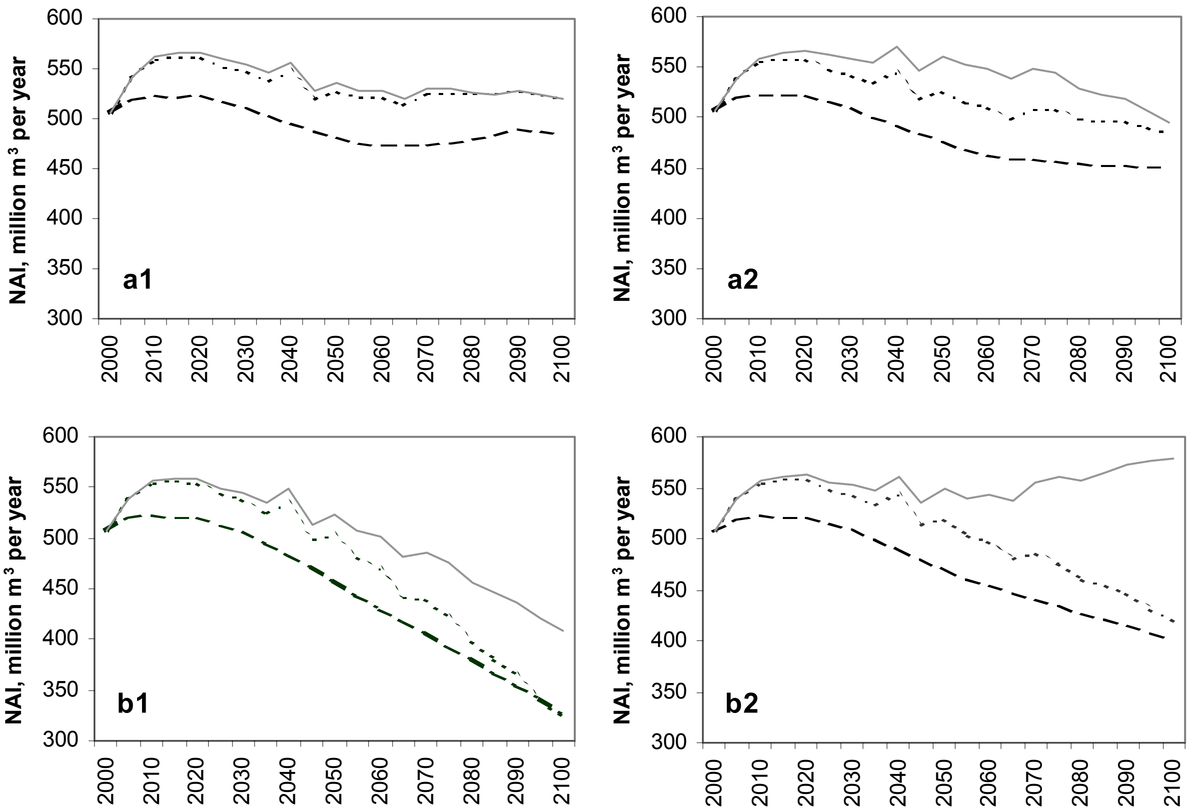

Figure 15. Development of the net annual increment (NAI) for the four SRES scenarios for current climate (long dashes), climate change (short dashes) and combined climate and land use change (grey solid line); sum for the 15 investigated countries.

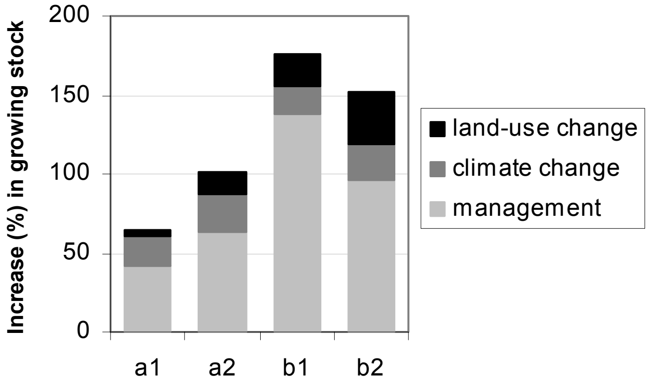

Figure 16. Relative increase in growing stock between 2000 and 2100, for the four SRES scenarios, and for the model runs with current climate, climate change, and climate change plus land use change; as a total for the 15 investigated countries.

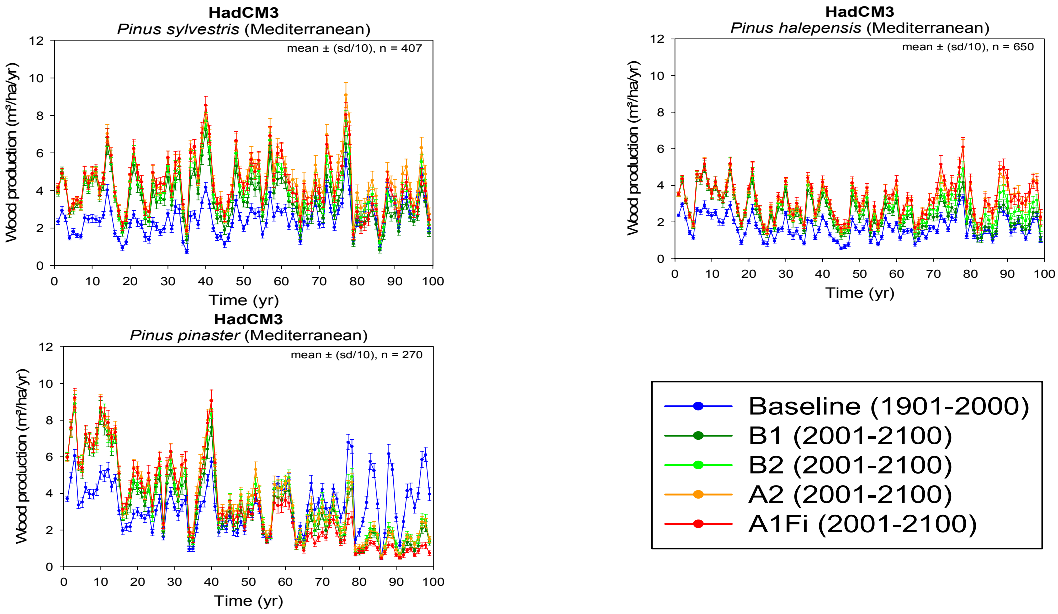

Figure 17. One hundred year series of mean values of wood production ($m^3ha^{-1}yr^{-1}$) under climate change (scenarios A1f, A2, B1 and B2 with climate model HadCM3) for the pine species *Pinus sylvestris*[39], *P. halepensis*[40] and *P. pinaster*[41] in the Mediterranean region. Bars represent standard deviation (standard deviation/10).

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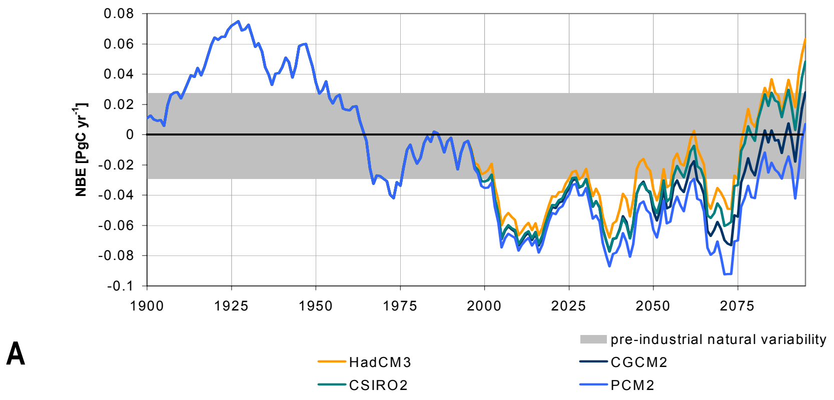
[39] *Pinus sylvestris*, common name: Scots pine.

[40] *Pinus halepensis*, common name: Aleppo pine

[41] *Pinus pinaster*, common name: Maritime pine



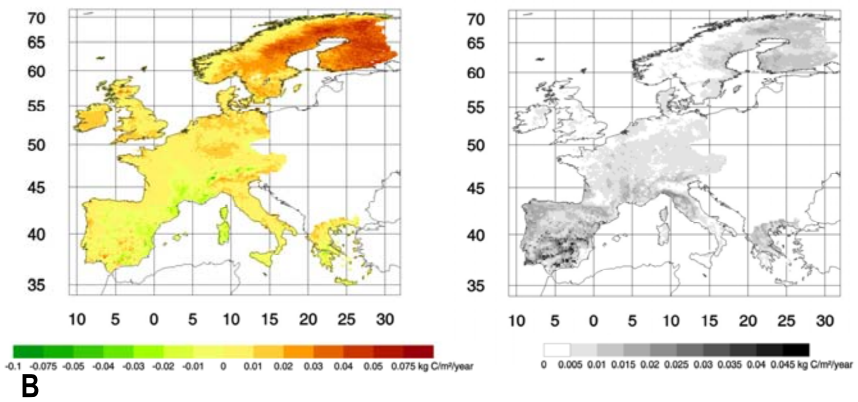


Figure 18. Variations in estimates of net biome exchange (NBE) over climate scenarios derived from four different climate models using the same emission scenarios (A2). **A.** Projections of total net biome exchange of the terrestrial biosphere over time in ATEAM-Europe, 1900-2100. Negative values denote fluxes into the terrestrial system, positive values denote fluxes out of the terrestrial system into the atmosphere. **B.** Changes in net biome exchange. Mean (left map) and standard deviation (right map) over four scenarios (A2 with four climate models) in ATEAM-Europe, 2071-2100 compared to 1971-2000. Negative values (green) indicates that flux of carbon to the terrestrial system in a grid cell is greater in 2071-2100 than in 1971-2000, positive values (red) indicate that this flux has decreased.

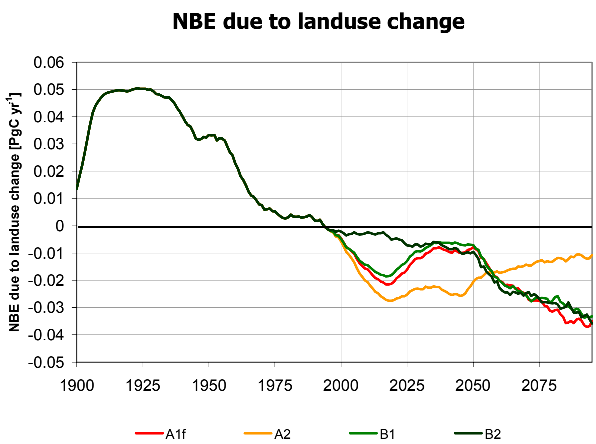
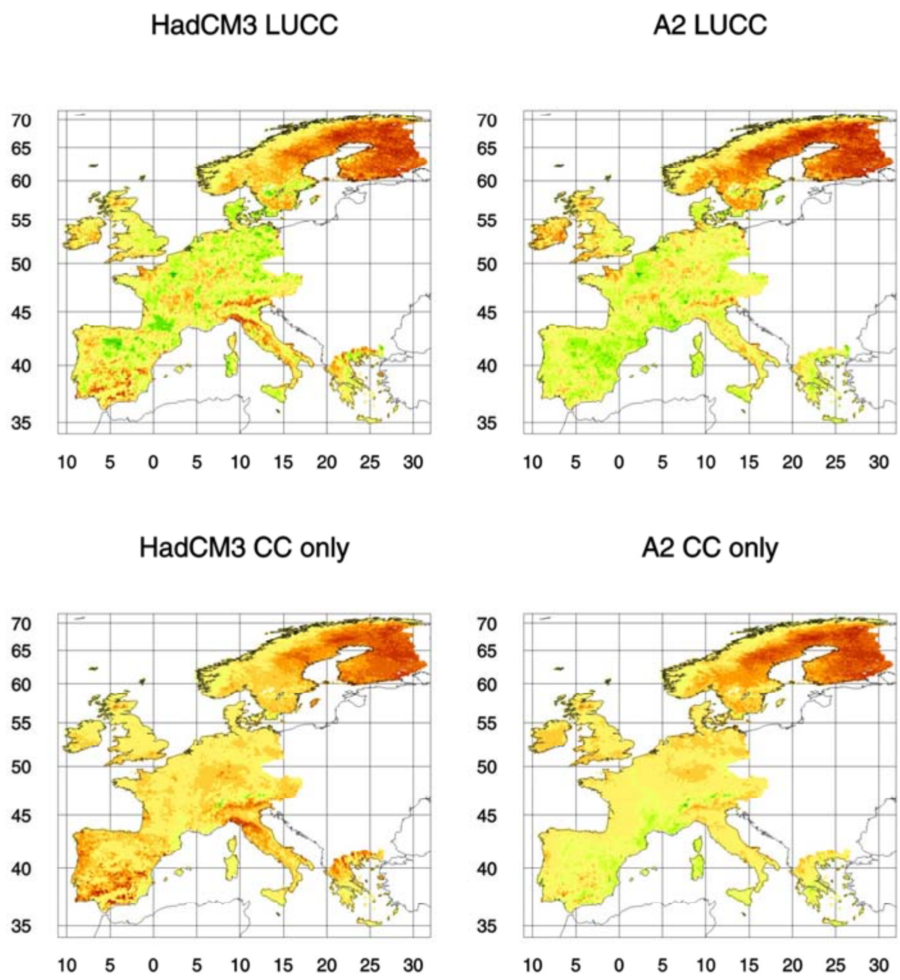
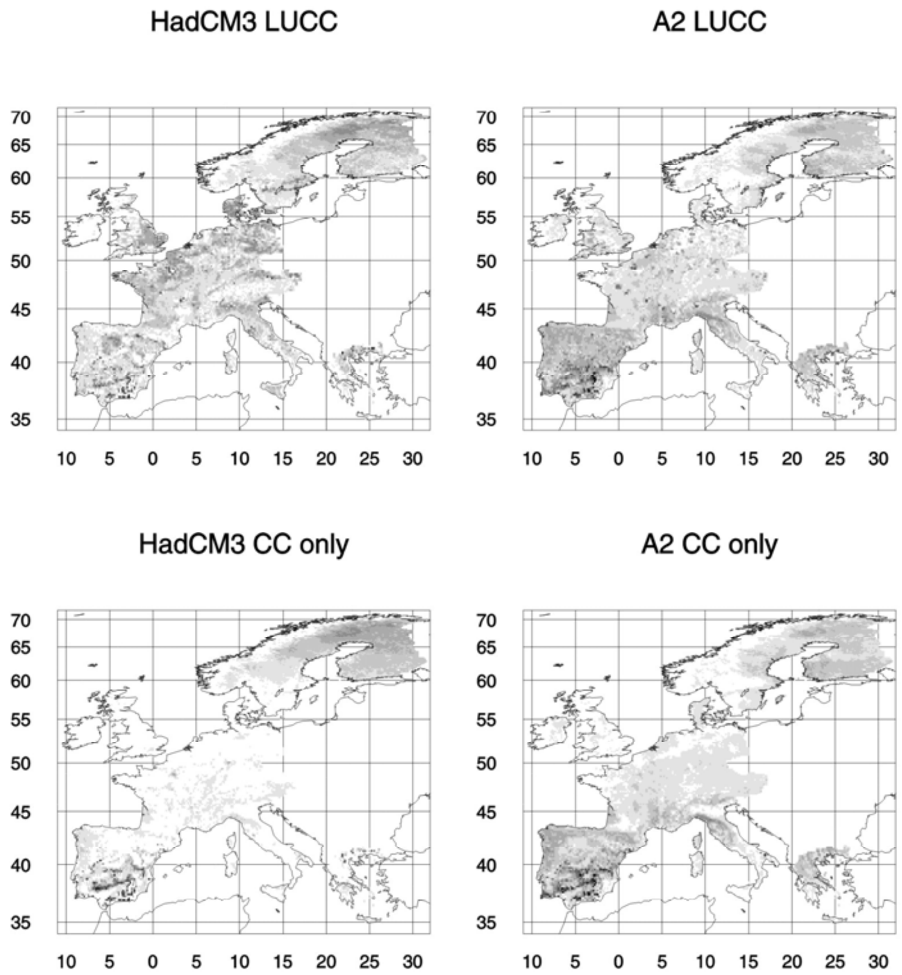


Figure 19. Total net biome exchange (NBE) of the terrestrial biosphere over time in ATEAM-Europe, accounting for land use change only. The estimates result from model runs driven by climate and land

use change, minus model runs driven by climate change only. Scenarios are based on HadCM3 runs for all four emission scenarios (A1f, A2, B1, B2). Negative values denote fluxes into the terrestrial system, positive values denote fluxes out of the terrestrial system into the atmosphere.



A



B

Figure 20. Net biome exchange (NBE) driven by climate change only (CC only) and climate change and land use change (LUCC) in Europe in 2071-2100. **A.** Mean values. **Maps on the left:** Mean over four scenarios representing socio-economic variation (A1f, A2, B1, B2 with climate model HadCM3). **Maps on the right:** Mean over four scenarios representing variation between different climate models (A2 with four climate models). **B.** Standard deviation. **Maps on the left:** Standard deviation over four scenarios representing socio-economic variation (A1f, A2, B1, B2 with climate model HadCM3). **Maps on the right:** Standard deviation over four scenarios representing variation between different climate models (A2 with four climate models).

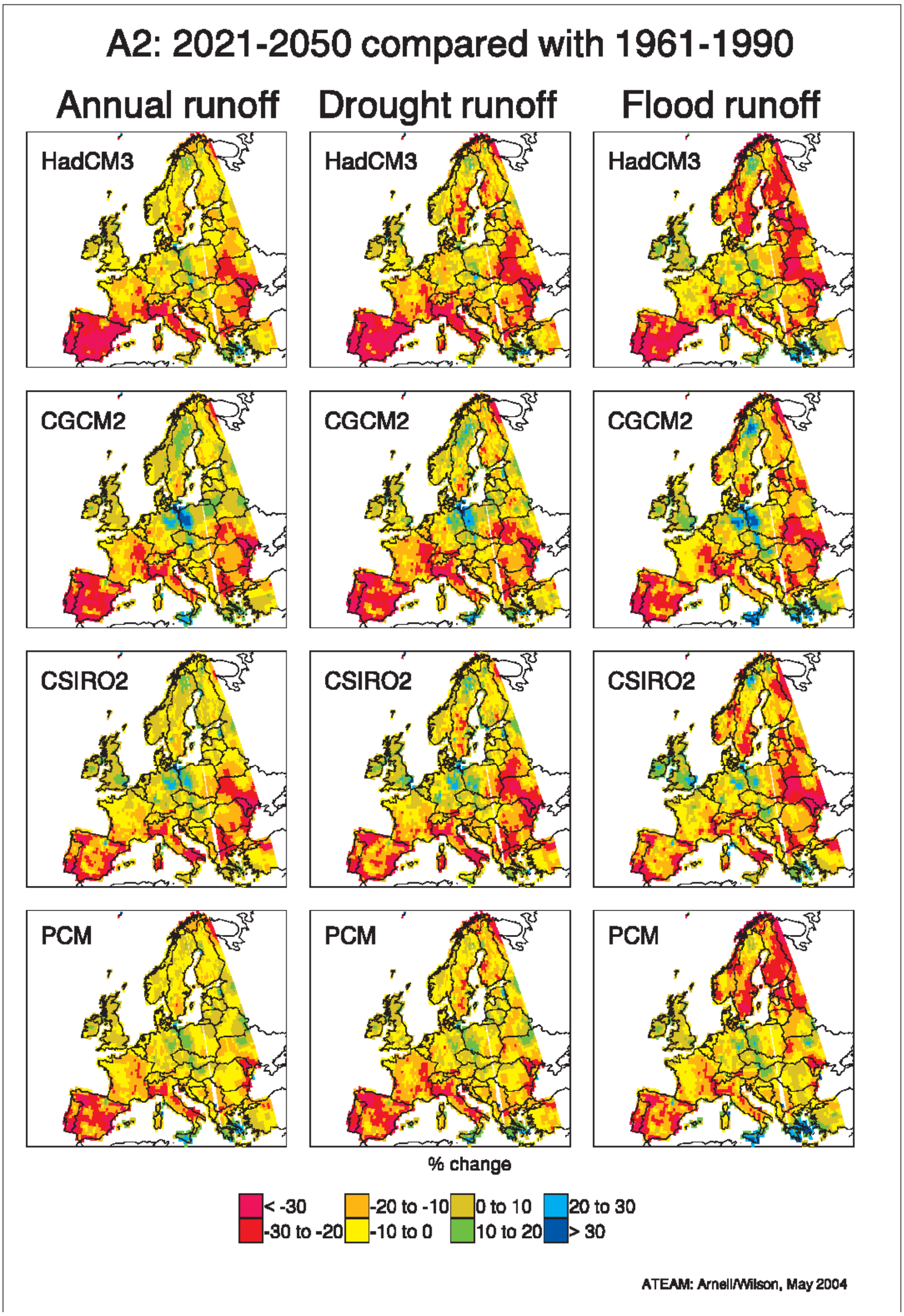
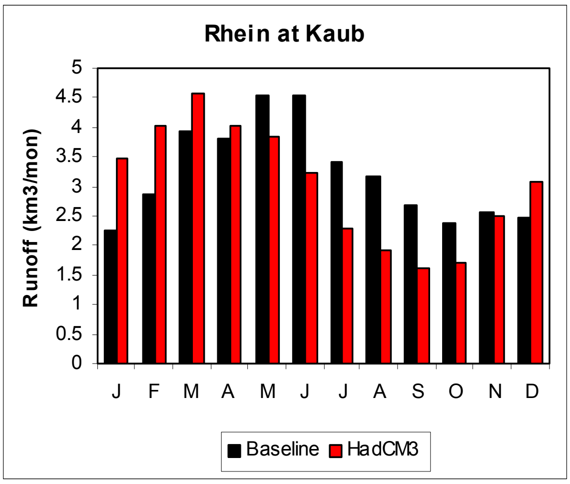
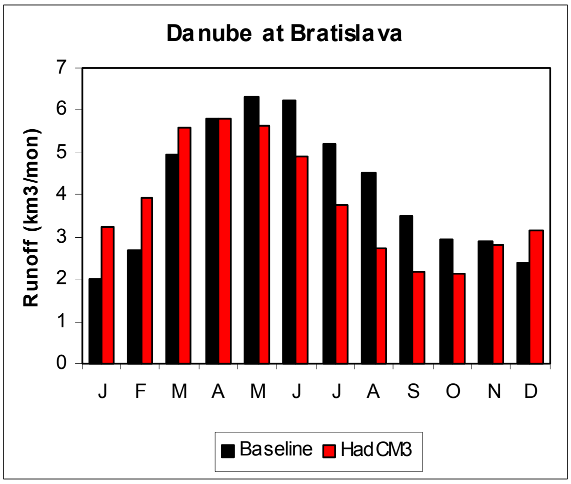


Figure 21. Change in average annual runoff, “drought” runoff and “flood” runoff across Europe, based on the A2 emissions scenario and four climate models (HadCM3, CGCM2, CSIRO2 and PCM).





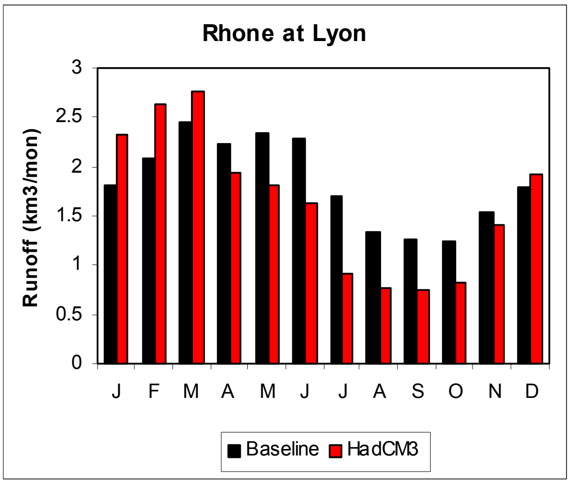


Figure 22. Mean monthly runoff along three major European rivers, under the current climate (baseline) and the 2021-2050 climate, calculated by climate model HadCM3 with A2 emissions.

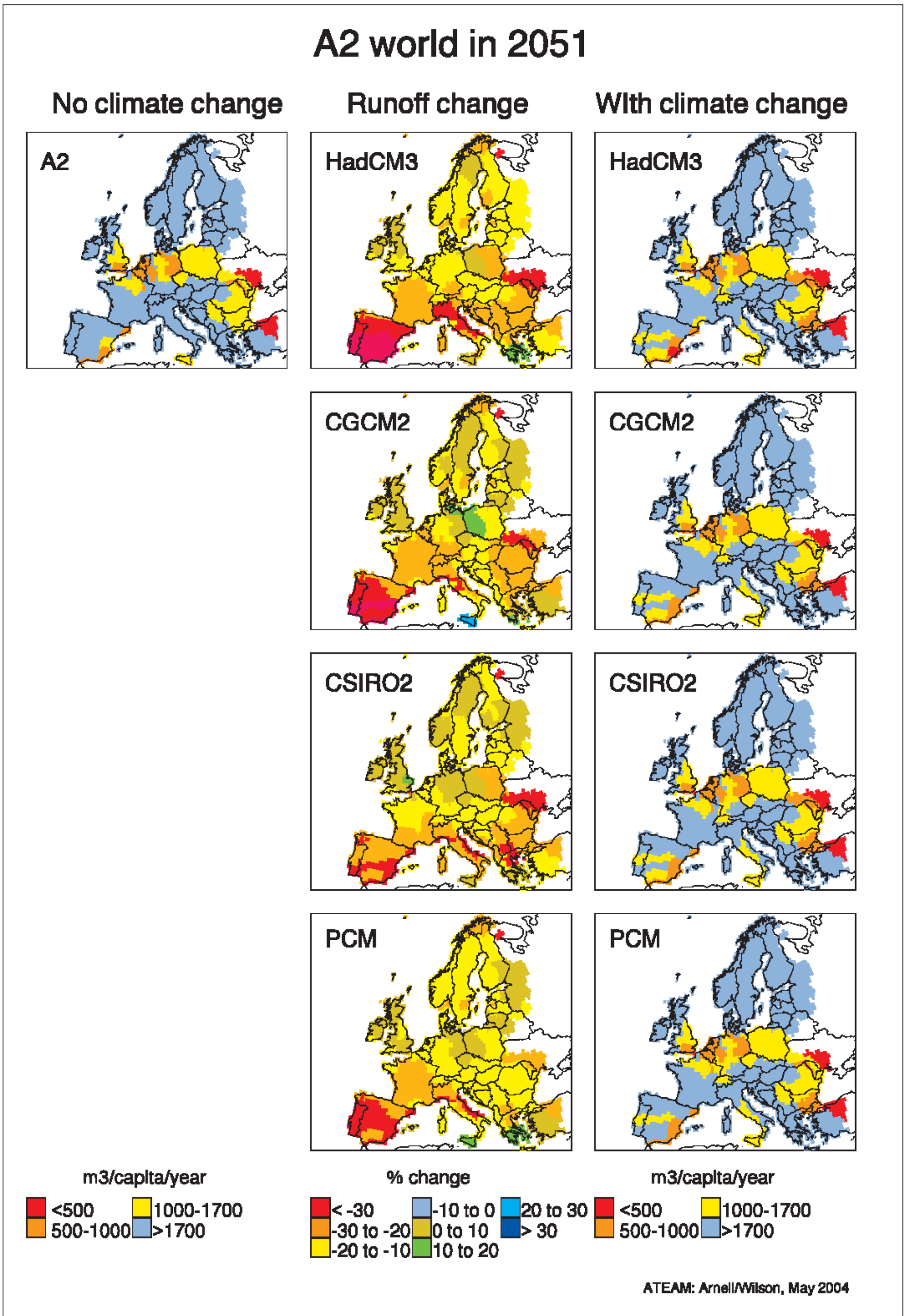


Figure 23. Water resources availability by major river basin across Europe in 2051 under the A2 world. The left-most panel shows the distribution of resources per capita (by major basin) with an A2 population in the absence of climate change. The central panels show the change (%) in basin average annual runoff under climate change calculated by the four climate models, and the right-most panels show the distribution of resources per capita ($m^3 capita^{-1} year^{-1}$) with climate change.

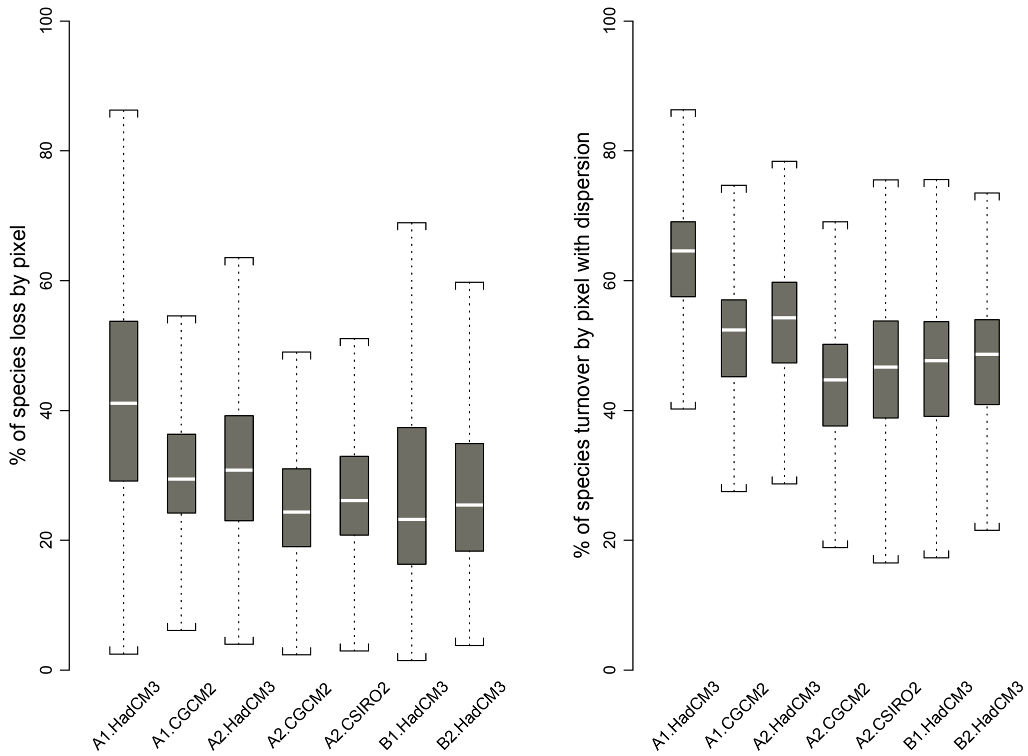


Figure 24. Percentage of species loss and turnover by pixel for 2080 under different climate change scenarios. In contrast to results from the other ATEAM sectors, the estimates shown here are based on a coarser spatial resolution of 50 x 50 km.

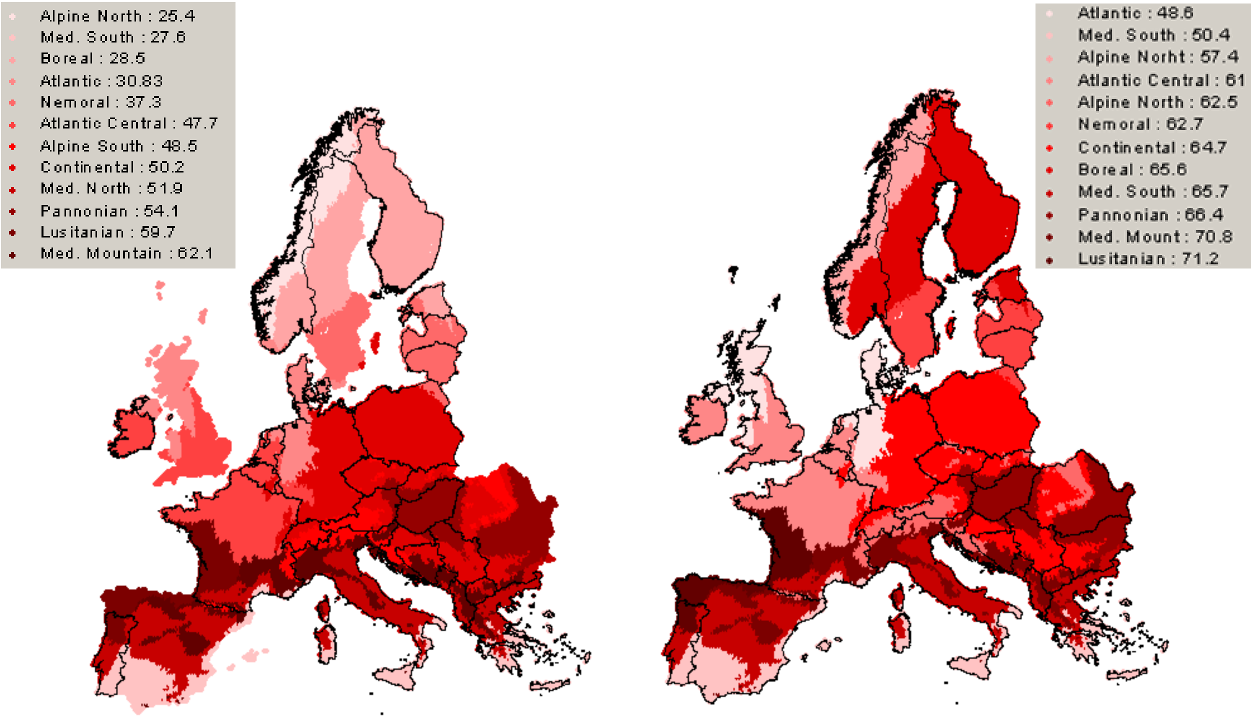


Figure 25. Mean percentage of species loss (left map) and species turnover with dispersal (right map) per environmental zone under the A1f-HadCM3 scenario in 2080. The respective scales give the value (%) per environmental zone. In contrast to results from the other ATEAM sectors, these maps have a coarser spatial resolution of 50 x 50 km.

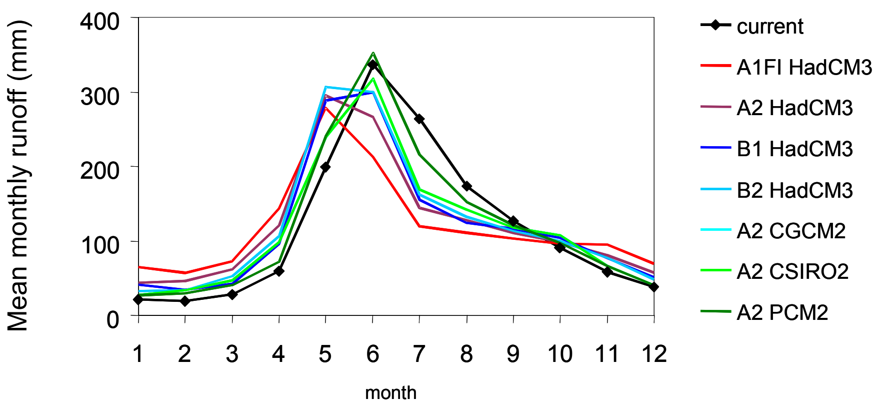


Figure 26. Stream flow regime (mean monthly runoff in millimetres (mm) over time) of Dischma valley for current and future (time slice 2050 – 2080) conditions.

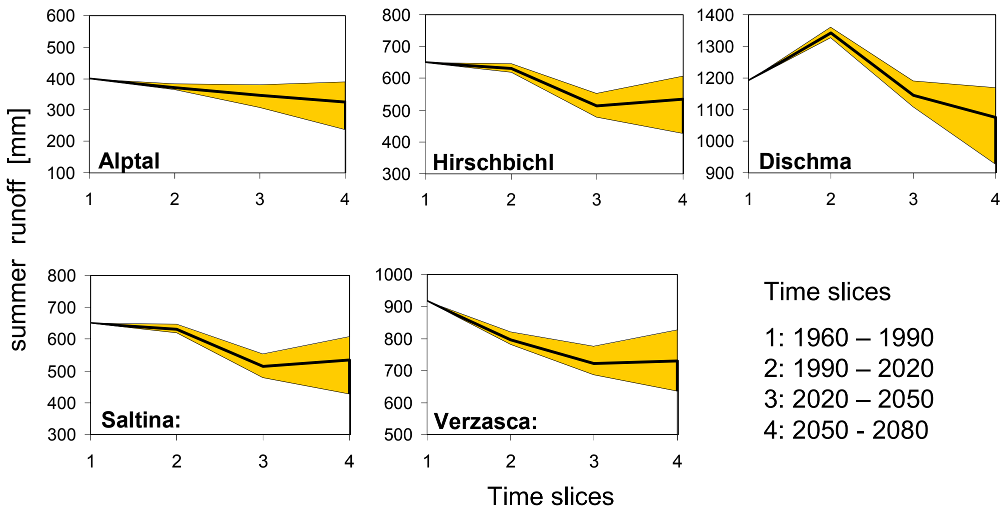


Figure 27. Summer river discharge (May to October) averaged over the three decades of the four time slices of ATEAM. The thick line gives the average summer river discharge of the seven different scenarios. The yellow area shows the maximum and minimum of the seven scenarios.

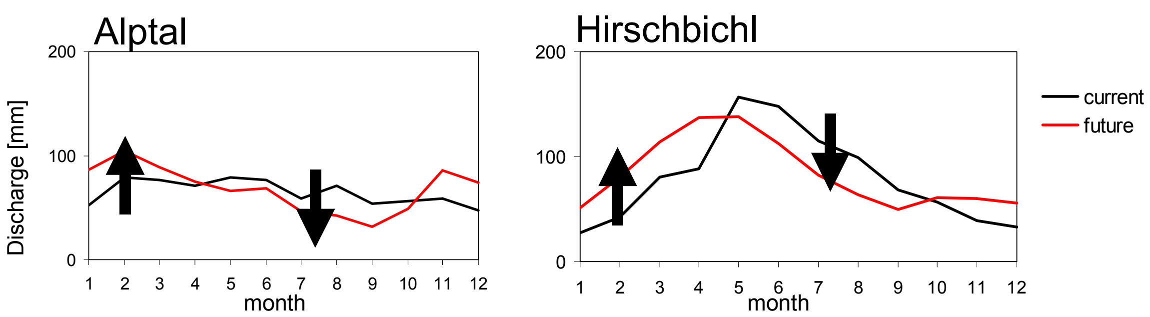


Figure 28. Stream flow regimes for the Alptal and the Hirschbichl catchment under current conditions and under future conditions (time slice 2050 – 2080, A2 HadCM3).

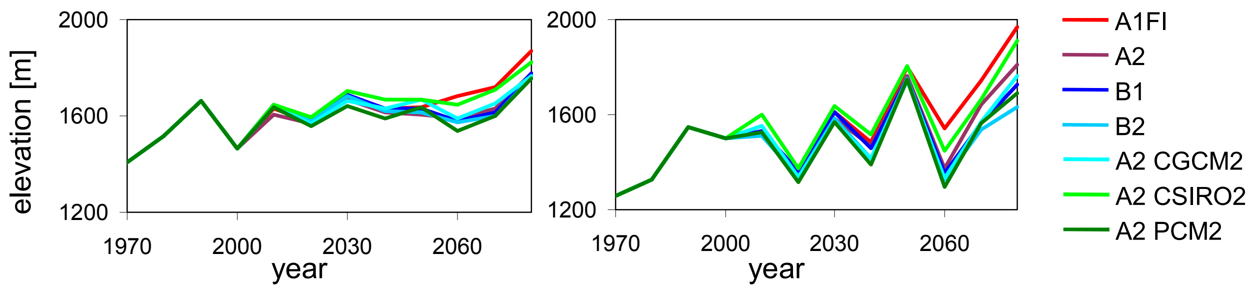


Figure 29. Elevation of snow line (elevation above which the snow cover is reliable) as projected for seven future climate scenarios. The left chart shows the Alptal catchment, the right chart shows the Verzacsa-Lavertezzo catchment.

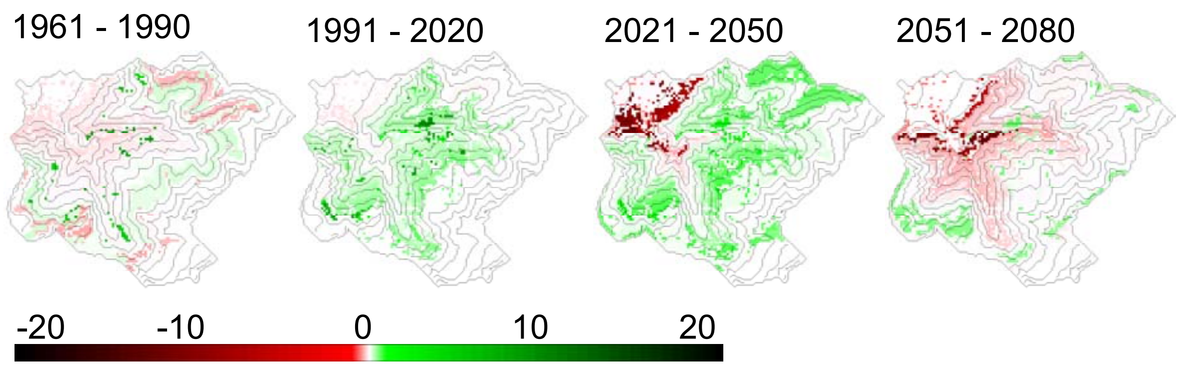


Figure 30. Changes in vegetation carbon storage (kg C m^{-2}) for the Saltina catchment at the four time slices of ATEAM for the A1f HadCM3 scenario. Dark green colours show a change in land use from grass to forest, dark red colours show areas where forests were converted into grassland.

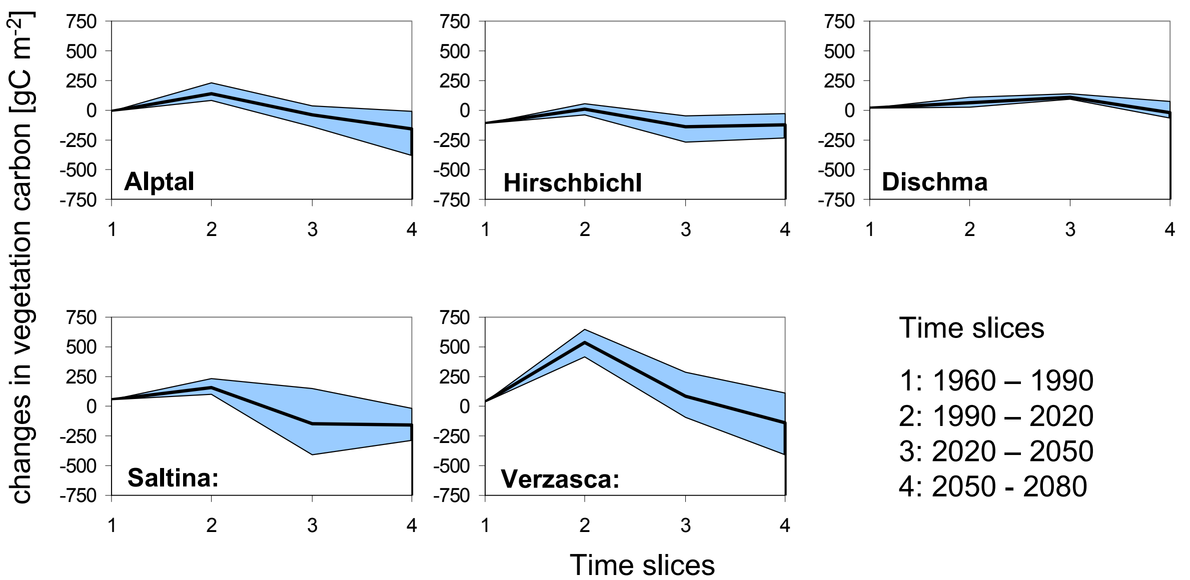


Figure 31. Changes in vegetation carbon storage (g C m^{-2}) in five mountain catchments (averages over the entire catchment) for the four time slices of ATEAM. The thick line gives the average vegetation carbon storage of the seven different scenarios. The blue area shows the maximum and minimum of the seven scenarios.

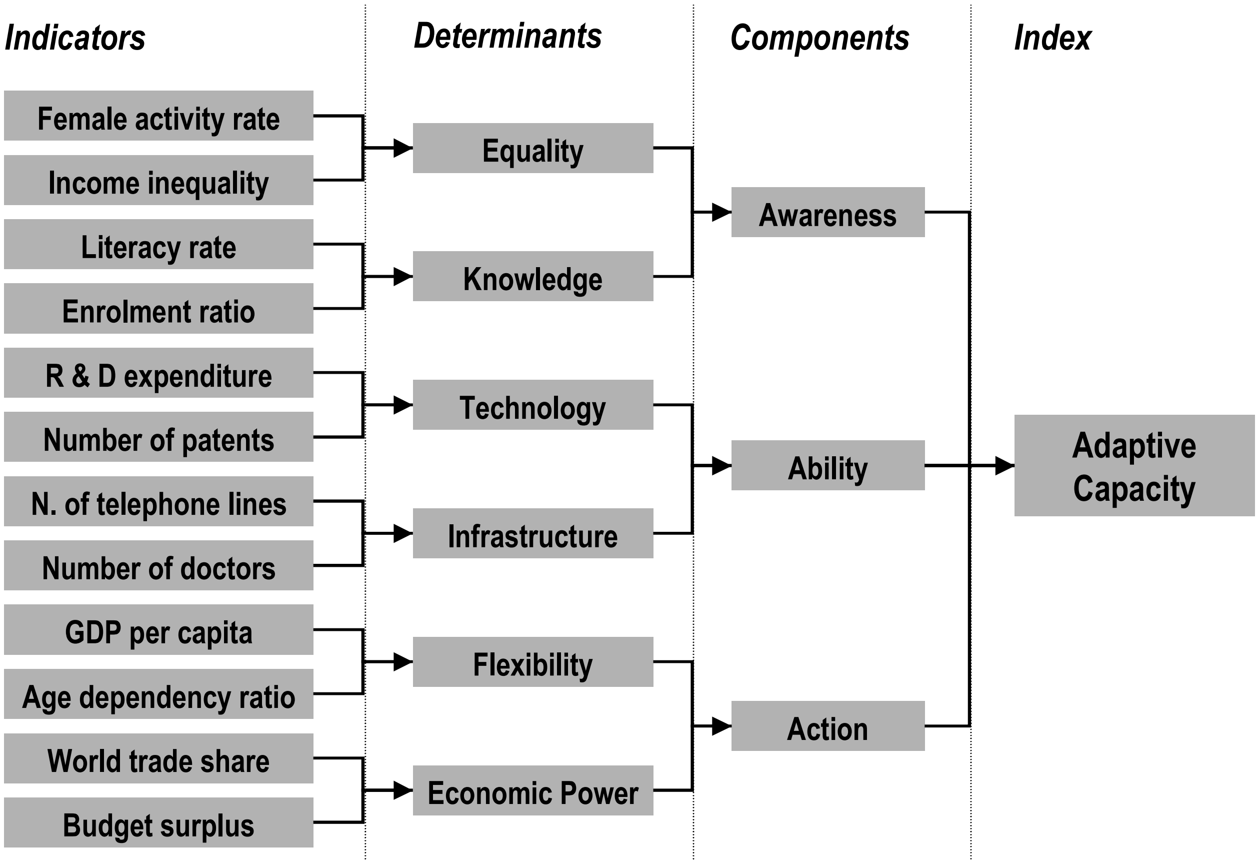


Figure 32. Conceptual framework of a three step aggregation of indicators, determinants and components of adaptive capacity into a generic adaptive capacity index. Enrolment ratio = Ratio of people enrolled in higher education programs; R & D expenditure = Research and Development expediture; N. of telephone lines = Number of telephone lines; GDP = Gross domestic product. See text for critical discussion.

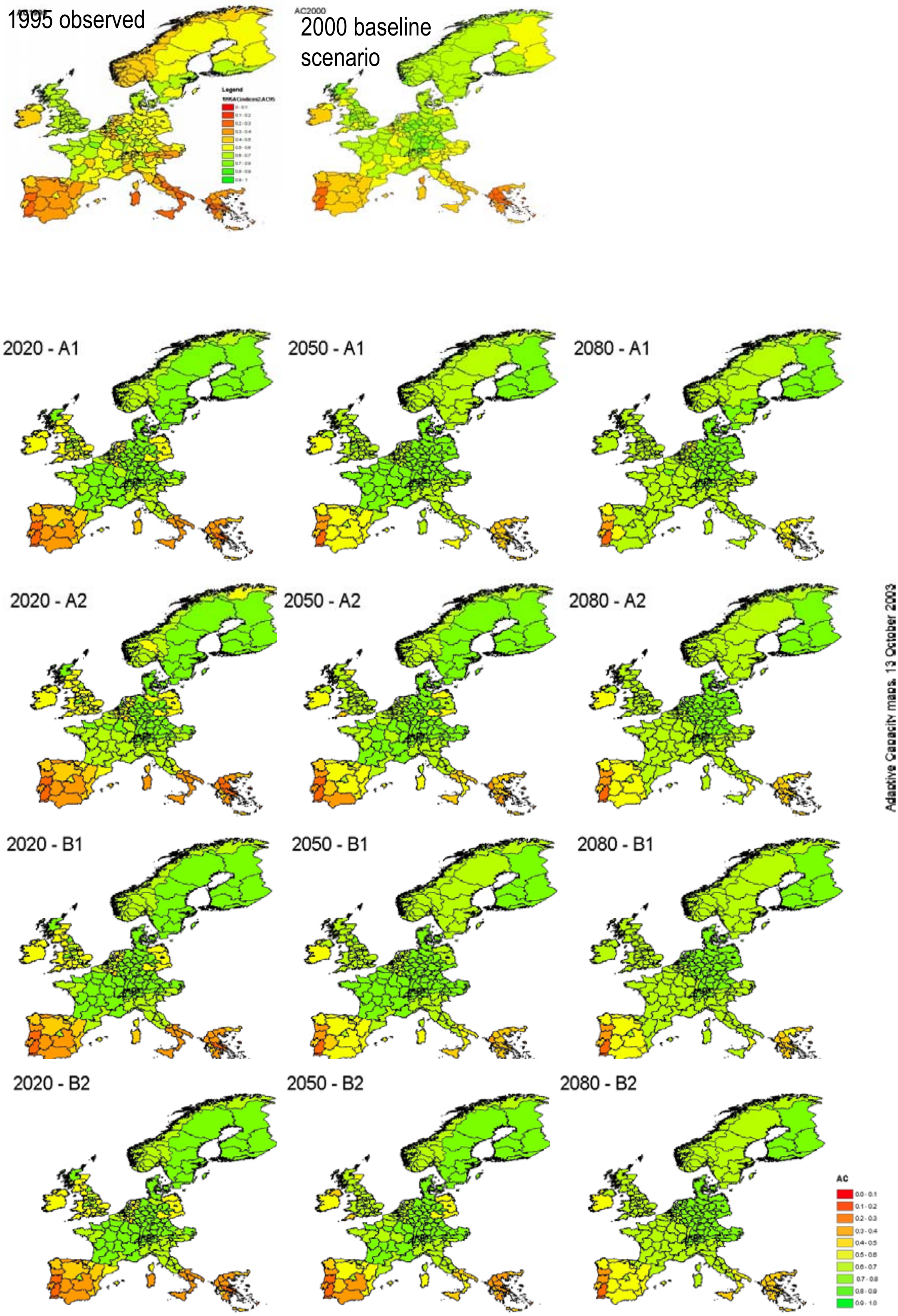


Figure 33. Preliminary maps of the adaptive capacity index (green = high adaptive capacity, red = low

adaptive capaqcity). Top row, calibration maps based on observed data (1995, left map) and extrapolated data (2000, baseline, right map). Rows 2-5 show the SRES scenarios A1f, A2, B1, B2 respectively, with the time slices 2020, 2050, 2080 in columns from left to right.

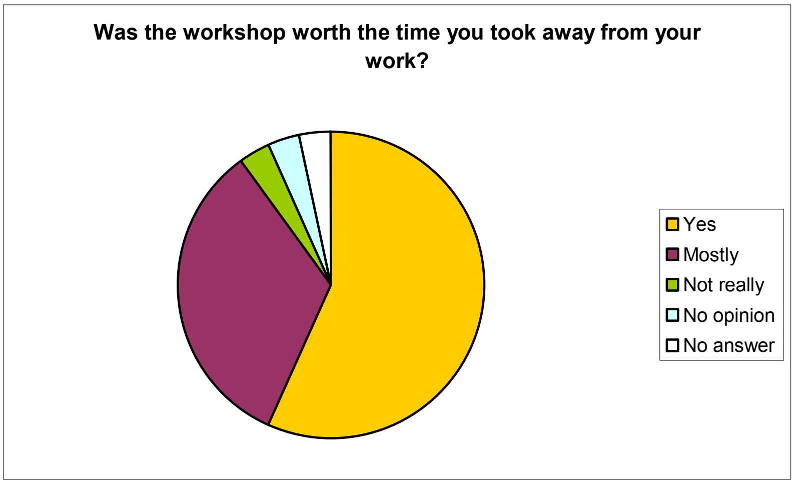


Figure 34. Stakeholders' responses to the question "Was the workshop worth the time you took away from your work?". Three workshops were evaluated, with 30 respondents from 41 questionnaires distributed.

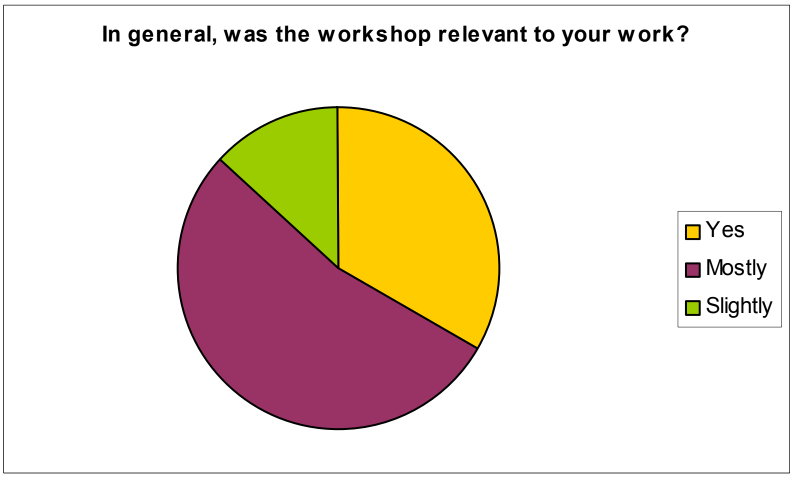


Figure 35. Stakeholders' responses to the question "In general, was the workshop relevant to your work?". Three workshops were evaluated, with 30 respondents from 41 questionnaires distributed.

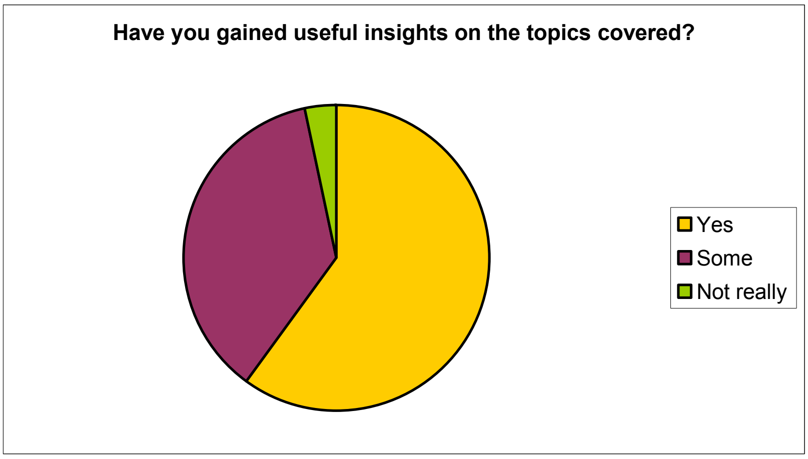


Figure 36. Stakeholders' responses to the question "Have you gained useful insights on the topics covered?". Three workshops were evaluated, with 30 respondents from 41 questionnaires distributed.

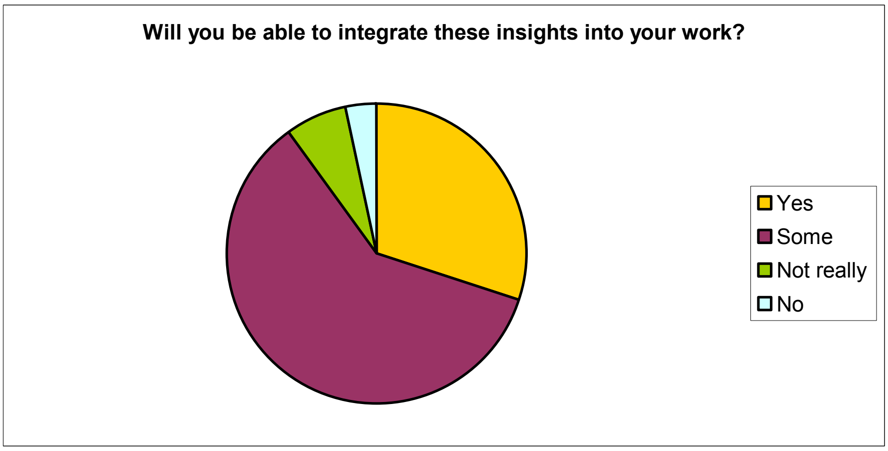


Figure 37. Stakeholders' responses to the question "Will you be able to integrate these insights into your work?". Three workshops were evaluated, with 30 respondents from 41 questionnaires distributed.

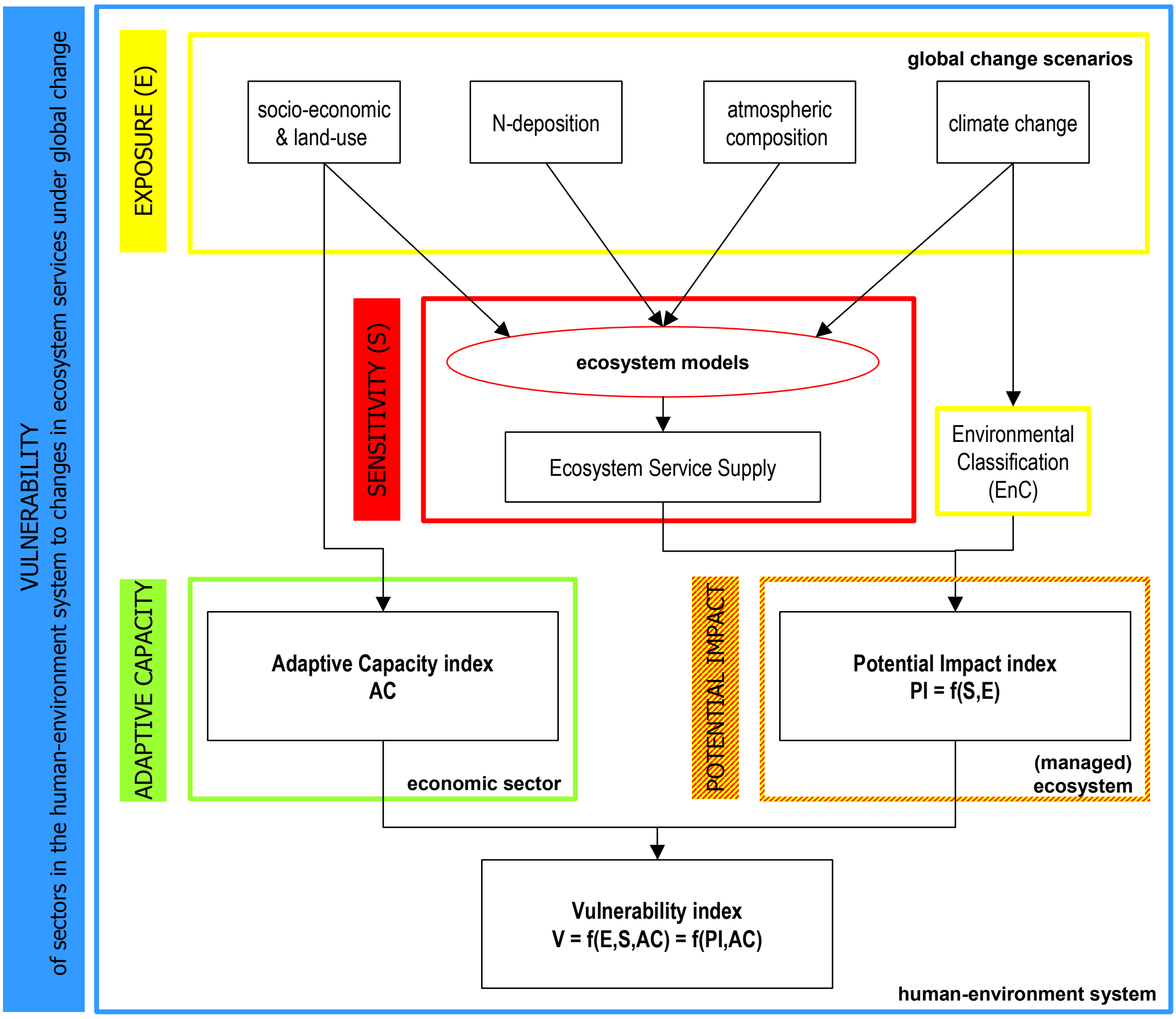


Figure 38. Summary of the ATEAM approach to quantify vulnerability. Global change scenarios of exposure are the drivers of a suite of ecosystem models that make projections for future ecosystem services supply for a 10'x10' spatial grid of Europe. Socio-economic scenarios are used to project developments in macro-scale adaptive capacity. The climate change scenarios are used to create a scheme for stratifying of ecosystem service supply in a regional environmental context (Potential Impact Index). Changes in the stratified ecosystem service supply compared to baseline conditions reflect the potential impact of a given location. The potential impact and adaptive capacity indices can be combined, at least visually, to create European maps of regional vulnerability to changes in ecosystem service supply.

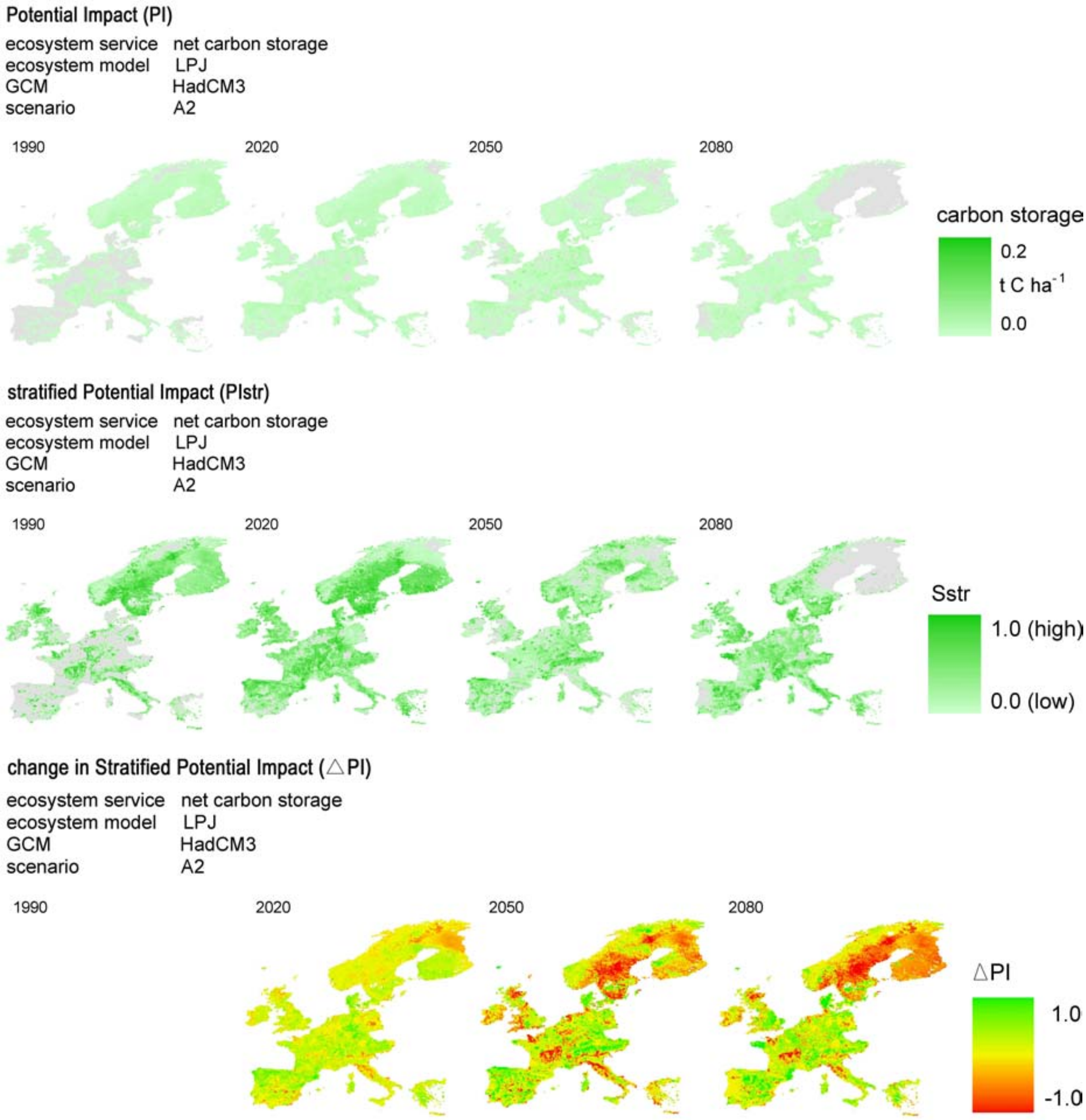


Figure 39. The potential impact maps are directly based on the model outputs for ecosystem service supply (in this case carbon storage). The stratified potential impact map shows more regional detail by putting the results into their environmental context (see text). The change in stratified potential impacts shows the stratified potential impacts through the 21st century, showing the time slices 2020, 2050 and 2080 relative to the 1990 baseline.

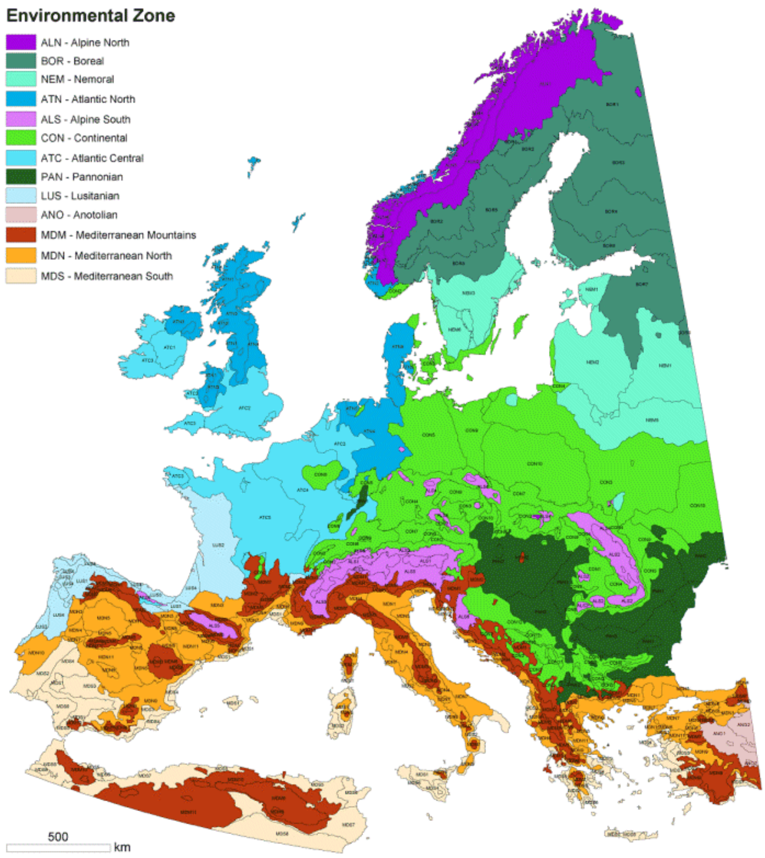


Figure 40. The Environmental Classification of Europe in eighty-four classes, aggregated to 13 Environmental Zones. Because certain classes do not necessarily fit traditional experience, in this classification strict statistical rules have been maintained, recognising these apparent inconsistencies, e.g. PAN in the Vosges and Schwarzwald and CON in southern Norway. Here we distinguish 13 Environmental Zones: ALN – Alpine North, BOR – Boreal, NEM – Nemoral, ATN – Atlantic North, ALS – Alpine South, CON – Continental, ATC – Atlantic Central, PAN – Pannonian, LUS – Lusitanian, ANO – Anotolian, MDM – Mediterranean Mountains, MDN – Mediterranean North, MDS – Mediterranean South.

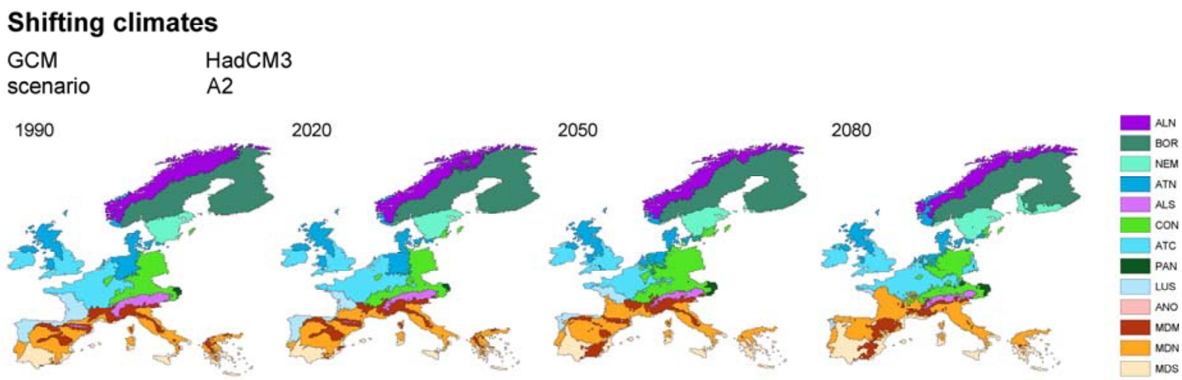


Figure 41. Climatic and topographic variables were statistically clustered into 84 environmental classes. By calculating discriminant functions for the classes they can be mapped for each global change scenario, resulting in maps of shifting environmental zones that can be used for stratification. Here we distinguish 13 Environmental Zones: ALN – Alpine North, BOR – Boreal, NEM – Nemoral, ATN – Atlantic North, ALS – Alpine South, CON – Continental, ATC – Atlantic Central, PAN – Pannonian, LUS – Lusitanian, ANO – Anotolian, MDM – Mediterranean Mountains, MDN – Mediterranean North, MDS – Mediterranean South.

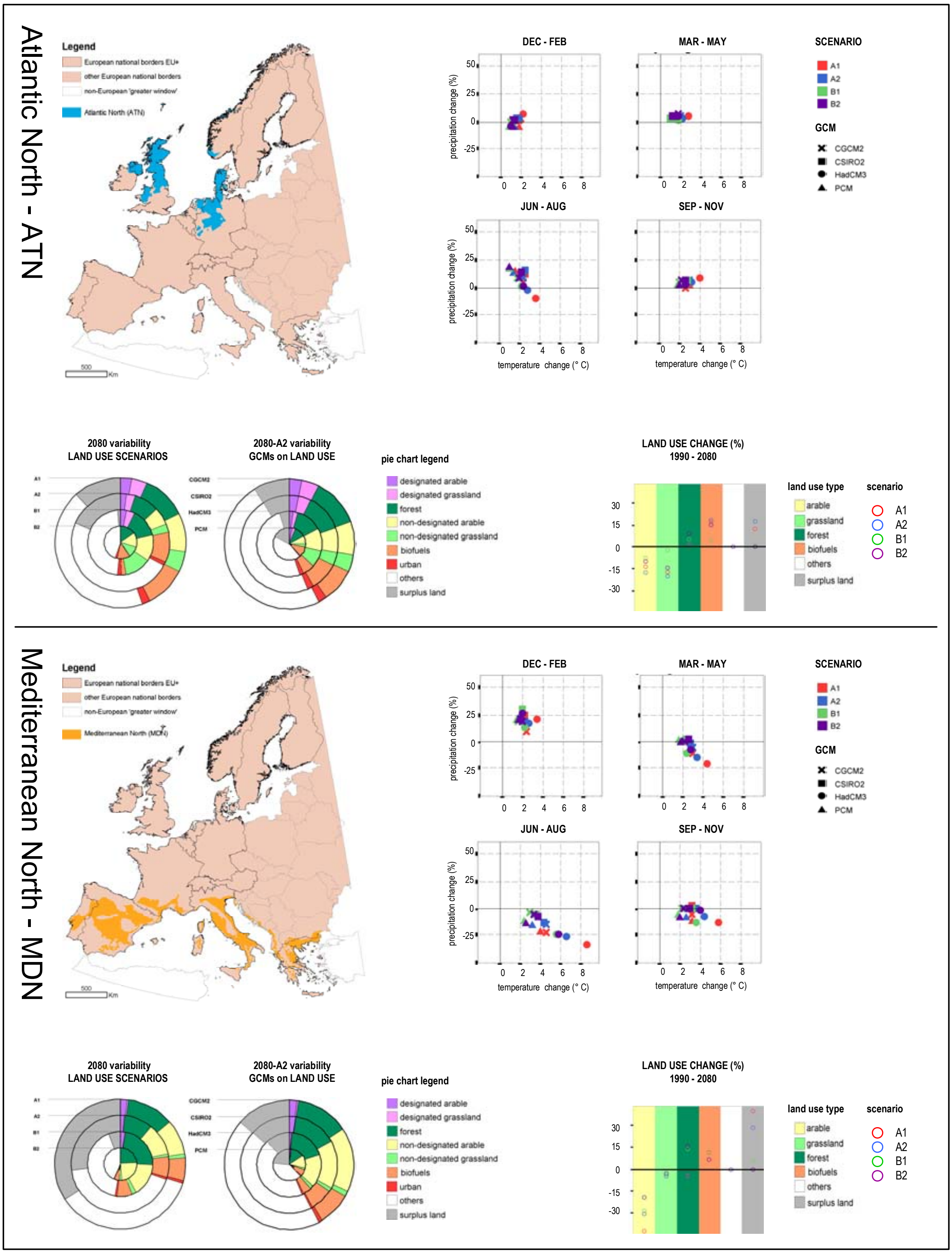


Figure 42. Summaries of the scenarios per Environmental Zone aids the interpretation of the scenarios. For instance, the two examples in this figure show that the variability in the climate change scenarios is greater in the Mediterranean North (MDN) than in the Atlantic North (ATN) and that there is considerable disagreement between the Global Circulation Models (GCMs) for the summer months in MDN. This figure also shows that land use changes are far greater in MDN.

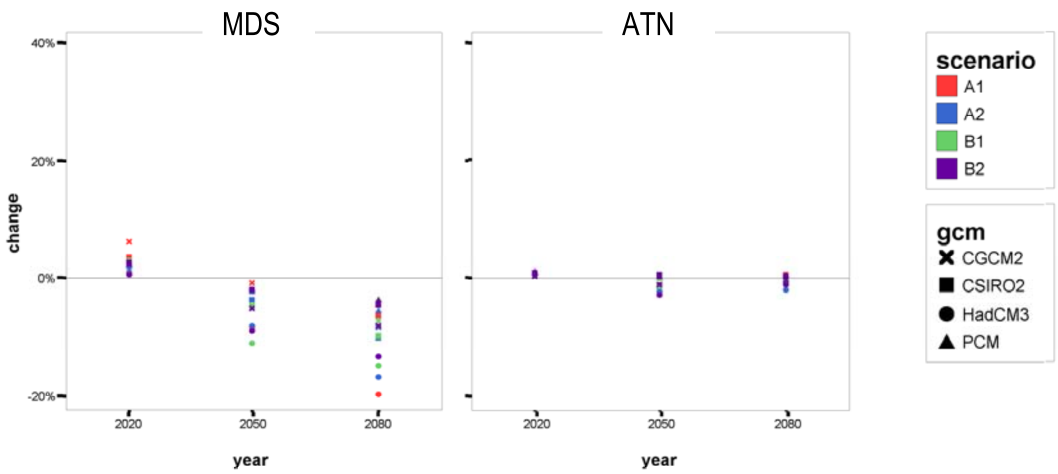


Figure 43. Summary of the changes in an ecosystem service by Environmental Zone. This figure shows the mean change in potential wheat yield compared to 1990 for Mediterranean South (MDS) and Atlantic North (ATN) for the four SRES scenarios and four Global Circulation Models (GCMs). In MDS potential wheat yield decrease dramatically, although there is considerable variability between scenarios and GCMs. In ATN wheat yield levels stay stable.

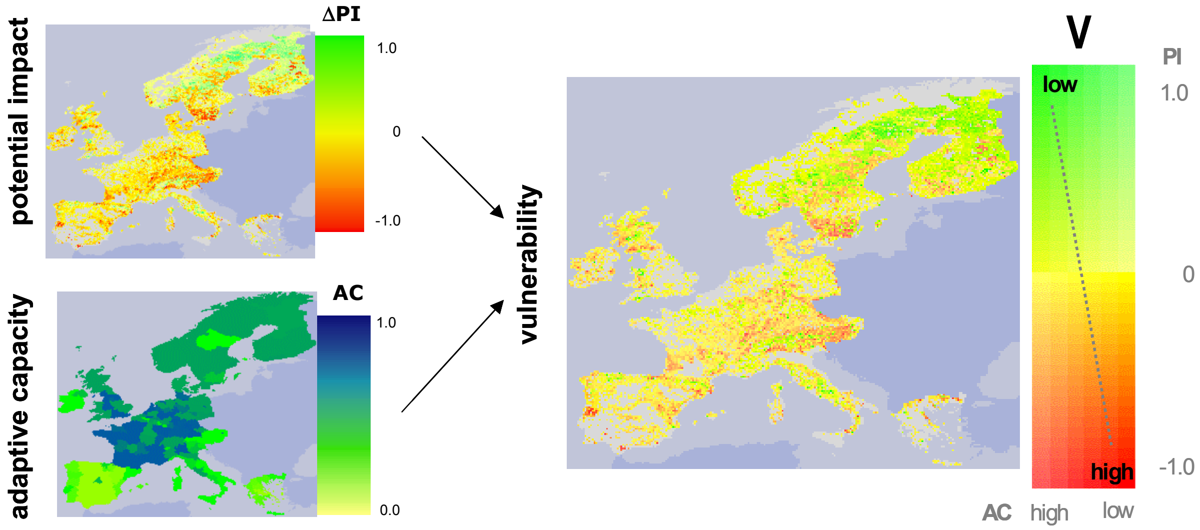


Figure 44. Vulnerability maps combine information about changes in potential impact (ΔPI) and adaptive capacity (AC), as illustrated by the legend. An decrease of stratified potential impact decreases vulnerability and visa versa. At the same time vulnerability is lowered by human adaptive capacity. In this visual overlay, the relationship between ΔPI and AC is not specified beyond high ΔPI and low AC result in high vulnerability. Furthermore, the scale has no unit – the map identifies areas to guide further analyses of the underlying data. The illustrative example given here is based on wood production in the Forestry sector in 2080, considering climate and land use based on A1 HadCM3.

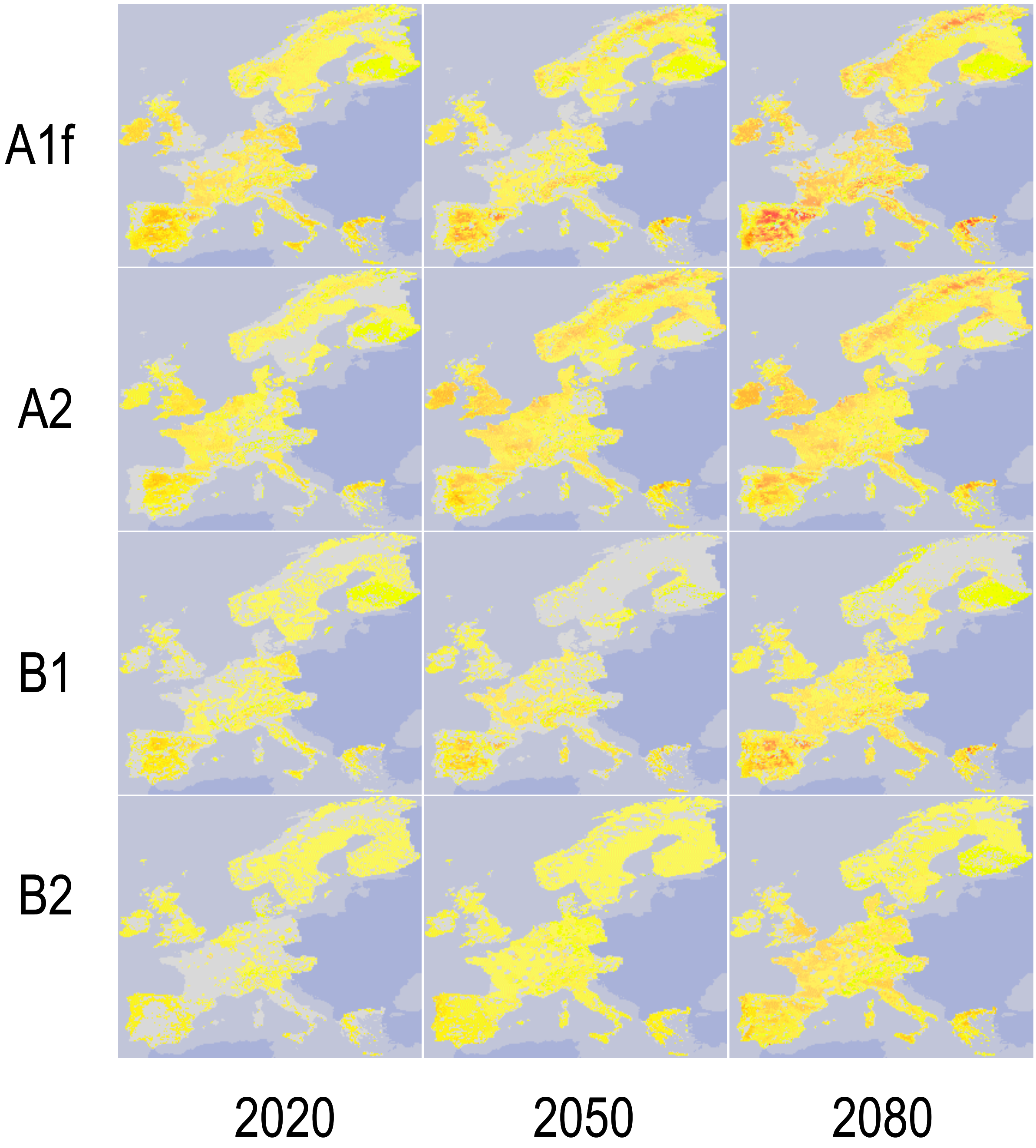


Figure 45. Vulnerability maps based on the ecosystem service “Farmer livelihood”, sector agriculture. The maps are based on changes in potential impacts on farmer livelihood relative to 1990 and the adaptive capacity index for the different scenarios and time slices. The legend of Figure 44 applies (red is vulnerable, green is not vulnerable; and grey means there is no change in vulnerability relative to 1990). Drivers were climate scenarios based on the general circulation model HadCM3 and the respective land use change for the storylines A1f, A2, B1, and B2.

Figure 46. The welcoming screen of the ATEAM mapping tool, a digital atlas containing ca. 3200 maps of vulnerability, as well as the underlying indicators, such as exposure, potential impact and adaptive capacity. In this tool, sectors, ecosystem services, scenarios and time slices can be selected and maps and summarising charts will be given on demand. Customised comparison of different scenarios, sectors, services and/or time slices is possible. Results can also be summarised by country or environmental zone.

Annex 4 - The ATEAM Stakeholder Database

The table shows three groups of stakeholders: first “Particpants”, these are stakeholders who participated in an ATEAM activity, then “Other invited/contacted stakeholders”, these were contacted and/or invited, but did not participate in any workshops, and then “Other identified stakeholder”, these have been found to be potentially interested in ATEAM but have not been contacted. The stakeholders are further sorted by sectors.

Title	Surname	Organisation	Expertise	Organisation's type	Scale of interest
PARTICIPANTS					
AGRICULTURE					
Dr.	Bryson	Velcourt Ltd. E-space South	Farmers’ management practices and needs	Sector consultancy	UK
Dr	Gatel	Association Générale des Producteurs de Blé	Farmers' management practices and needs Biomass energy	Sectoral representative	France
Dr	Gosse	Institut National de Recherche Agronomique	Agricultural modelling and biomass energy	Public body/academic	France
Dr	Lellahi	Institut Technique des Céréales et des Fourrages	Agricultural modelling and biomass energy	Public body/academic	France
Dr	de Vries	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Farmers’ management practices and needs Biomass energy	Sectoral representative	Europe
BIODIVERSITY					
Dr	Alkemade	Netherlands Environmental Assessment Agency	Biodiversity and natural protection issues	Public body/academic	Europe
Dr	Berry	Environmental Change Institute,	Biodiversity and natural protection issues	Public body/academic	UK
Mr	Franz	Nationalpark Berchtesgaden	Natural park management	Public body/resource management	Alpine
Mr	Frapa	Parc naturel régional du Lubéron	Natural park management	Public body/resource management	Mediterranean
Dr	Harley	English Nature	Climate and conservation policy	Public body/advise to policy	UK
Dr	Heimo	Environment – Ecology – Forestry	Natural resources development and environmental conservation	Sector consultancy	Europe/Global
Dr	Lanchberry	Royal Society for the Protection of Birds	Biodiversity and natural protection issues	NGO	UK
Dr	Jongman	Alterra Green World Research	Landscape ecology	Public body/academic	Europe
Ms	Richard	European Topic Centre in Nature Conservation	Biodiversity and natural protection issues	Public body/advise to policy	Europe
		Flora Europea	Ecological monitoring	Public body/academic	Europe
		Parc National des Écrins	Natural park management	Public body/resource management	Alpine
CARBON STORAGE/POLICY					
Mr	Duwe	Climate Network Europe	Climate policy specialist	Independent/umbrella organisation	Europe/Global

Mr	Hare	Greenpeace international	Environmental, climate and agricultural policy information needs	NGO	Europe/Global
Dr	Haxeltine	Tyndall Centre	Integrated climate impact assessment - science policy interface	Public body/academic	Europe/Global
Mr	Hoogeveen	European Environment Agency	Environmental, climate and agricultural policy information needs	Public body/advise to policy	Europe/Global
Ms	Kinkead	EcoSecurities	Carbon sequestration and clean development mechanisms	Sector consultancy	Europe/Global
Dr	Mahrenholz	Unweltbundesamt	Climate and environmental policy needs	Public body/advise to policy	Germany
Dr	Ribeiro	European Environment Agency	Environmental, climate and agricultural policy information needs	Public body/advise to policy	Europe/Global
Dr	Rosa	Universidade de Lisboa	Environmental policy	Public body/academic	Mediterranean
Dr	Sartorius	Unweltbundesamt	Climate and environmental policy needs	Public body/advise to policy	Germany
Ir	Verweij	FACE Foundation	Carbon sequestration and clean development mechanisms	NGO	Europe/Global
FORESTRY					
Ms	Baiges Zapater	Centre de la Propietat Forestal	Forestry management and needs	Public body/resource management	Mediterranean
Mr	Botey	Consorci Forestal de Catalunya/ Confederation of Spanish Forest Owners/ Confederation of European Forest Owner/ Pan European Forest Certification Council/ Cork and Non-wood products Working Group in the EU Advisory Forest & Cork Committee	Forestry management and needs	Sectoral representative	Mediterranean
Prof. Dr.	Bröker	Fachhochschule Eberswalde, FB Holztechnik	Forestry management and forest industry	Public body/academic	Germany/Brandenburg
Ms	Cervera	Centre de la Propietat Forestal	Forestry management and needs	Public body/resource management	Mediterranean
Mr	Girard	European Land Owner association	Forest and agricultural land management	Sectoral representative	Europe
Mr	Hafemann	Landesforstanstalt Eberswalde	Forestry policy and management	Public body/advise to policy	Germany/Brandenburg
Mr	Hartzsch	Schutzgemeinschaft Deutscher Wald (SDW)	Forestry conservation	Public body/advise to policy	Germany/Brandenburg
Ms	Heinitz	Ministerium für Landwirtschaft, Umweltschutz und Raumordnung, Abt. Forst	Forest policy and management	Public body/advise to policy	Germany/Brandenburg
Ms	Krause	Waldbesitzerverband Brandenburg	Forestry management and needs	Sectoral representative	Germany/Brandenburg
Mr	Lacour	AFOCEL - Laboratoire Economie et Compétitivité / COPACEL - Confederation française de l'Insdustrie des Papiers, Cartons et Celluloses/ CEPI -Confederation of European Paper Industries	Forestry management and needs	Sectoral representative	Europe
Mr	Luft	Lehroberförsterei Eberswalde	Forestry ecology and management	Public body/academic	Germany/Brandenburg
Mr	Müller	Landesforstanstalt Eberswalde, Ltr. Waldentwicklungsplanung	Forestry policy and management	Public body/advise to policy	Germany/Brandenburg

Mr	Mohr	Forstlicher Dienstleistungen; Wald, Umwelt, Mensch	Forestry conservation and management	Sector consultancy	Germany/Brandenburg
Prof. Dr.	Murach	Fachhochschule Eberswalde, FB Forst	Forest ecology and engineering	Public body/academic	Germany/Brandenburg
Mr	Nyström	Swedish Bioenergy Association (SVEBIO)/ European Biomass Association (AEBIOM)	Developments on bioenergy	Sectoral representative	Scandinavia
Mr	Pries	NABU Landesverband Brandenburg	Environmental conservation	NGO	Germany/Brandenburg
Mr	Scholz	Confederation of European Forest Owners	Forestry management and needs	Sectoral representative	Germany
Mr	Valtanen	Finnish Forest Industries Federation Confederation of European Paper Industries	Forest and paper industry	Sectoral representative	Scandinavia
Dr	Wagener-Lohse	ZAB Zukunftsagentur Brandenburg	Advise to forest industry and businesses	Sector consultancy	Germany/Brandenburg
JOURNALISTS					
Ms	Dehmer	Der Tagesspiegel	Climate change, environmental and scientific issues	Media	Germany
Ms	Schibilsky	Ostdeutscher Rundfunk Brandenburg	Environmental issues	Media	Germany
MOUNTAIN ENVIRONMENTS					
Dr	Hauenstein	Schweizerischer Wasserwirtschaftsverband	Alpine water management and needs	Independent/umbrella organisation	Alpine
Mr	Kreiliger	Bergbahnen Disentis AG	Alpine tourism and opportunities	Private business	Alpine
Mr	Revaz	CIPRA International	Alpine nature protection issues	independent/umbrella organisation	Alpine
Dr	Vogel	Nationalpark Berchtesgaden Réseau Alpin des Espaces Protégés	Alpine natural park management	Public body/resource management independent/umbrella organisation	Alpine
Dr	Volz	Swiss Agency for the Environment, Forests and Landscape	Policy information needs	Public body/advise to policy	Alpine
TOURISM					
Ms	Capone	Associazione Cultura Turismo Ambiente	Sustainable tourism issues	Sector consultancy	Mediterranean
Mr	Sillence	INPECO	Sustainable tourism issues	Sector consultancy	Mediterranean
WATER					
Dr	Butts	DHI Water & Environment	Water management	Sector consultancy	Europe
Dr	Green	Wessex Water	Water management	Private business	UK
Mr	Johansson	Euroelectric	Hydroelectricity generation	Private business	Europe
Dr.	Weigert	Wasserforschung e.V. – Association for Interdisciplinary Water Research Berlin Centre of Competence for Water (part of Veolia Water)	Water management	Public body/academic	Germany
OTHER INVITED/CONTACTED STAKEHOLDERS					
AGRICULTURE					
Mr	Carter		Farmer's management practices and needs, biomass energy	Private business	UK

Mr	Clarke	Assured Food Standards	Agro-industry and food standards	Independent/umbrella organisation	UK
Ms	Dejonckheere	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Farmers' management practices and needs	Sectoral representative	Europe
Dr	Feiter	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Farmers' management practices and needs	Sectoral representative	Europe
Mr	Gehrke	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Farmers' management practices and needs	Sectoral representative	Europe
Mr	Hedley	Country Land and Business Association	Agri-environmental and nature protection issues	Sectoral representative	UK
Mr	Lefaucheux	Syngenta International AG	Agri-environmental and nature protection issues	Private business	UK
Ms	Mitchell	UK National Farmers Union	Farmers' management practices and needs	Sectoral representative	UK
Ms	Olmeda-Hodge	Country Land and Business Association	Farmers' management practices and needs	Sectoral representative	UK
Ms	Ribera Bonifait	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Farmers' management practices and needs	Sectoral representative	Europe
Ms	Whyte	National Union of Farmers	Farmers' management practices and needs	Sectoral representative	UK
Dr	Williams	Home-Grown Cereals Authority	Farmers' management practices and needs	Public body/resource management	UK
BIODIVERSITY					
Ms	Arduino	WWF Italia	Biodiversity and natural protection issues	NGO	Mediterranean
Mr	Ash	UNEP-WCMC	Millennium Ecosystem Assessment	Public body/advise to policy	Europe/Global
Dr	Caldecott	UNEP-WCMC	Millinium Ecosystem Assessment	Public body/advise to policy	Europe/Global
Dr	Campling	EEA	Biodiversity and natural protection issues	Public body/advise to policy	Europe/Global
Ms	Cibien	Secrétariat scientifique du MAB France	Natural park management	Public body/resource management	Europe
Ms	Condé	European Topic Centre in Nature Conservation	Biodiversity and natural protection issues	Public body/advise to policy	Europe
Dr	de Groot	Wageningen University	Ecosystem functions and valuation	Public body/academic	Europe
Ms	Heath	BirdLife International	Biodiversity and natural protection issues	NGO	Europe/Global
Mr	Jacques	IUCN - World Conservation Union	Biodiversity and natural protection issues	Public body/advise to policy	Global
Dr	Jalbert	Station Biologique de la Tour du Valat	Ecological monitoring	Public body/academic	France
Mr	Grégoire	Parc Naturel Régional du Lubéron	Natural park management	Public body/resource management	Mediterranean
Dr	Kapos	UNEP-WCMC	Millinium Ecosystem Assessment	Public body/advise to policy	Europe/Global

Dr	Miles	UNEP-WCMC	Millinium Ecosystem Assessment	Public body/advise to policy	Europe/Global
Mr	Olivier	Parc National du Mercantour	Natural park management	Public body/resource management	Mediterranean
Dr	Thonell	UNEP-WCMC	Millinium Ecosystem Assessment	Public body/advise to policy	Europe/Global
Dr	Zöckler	UNEP-WCMC	Millinium Ecosystem Assessment	Public body/advise to policy	Europe/Global
CARBON STORAGE/POLICY					
Mr	Bradley	Climate Network Europe	Environmental and climate policy	Independent/umbrella organisation	Europe/Global
Mr	Fehse	EcoSecurities	Carbon trading - clean development mechanisms	Sector consultancy	Europe/Global
Mr	Jossart	Université Louvain-la-Neuve	Biomass energy	Public body/academic	Europe
Mr	Larsson	European Environment Agency	European environment policy, dissemination	Public body/advise to policy	Europe/Global
Mr	Martens	EcoSecurities	Carbon trading - clean development mechanisms	Sector consultancy	Europe/Global
Ms	Medina Gomez	Ecosecurities	Biomass and renewable energy	Sector consultancy	Global
	OECD Paris	Organisation for Economic Co-operation and Development	European trade and policy	Independent/umbrella organisation	Europe/global
	OECD Berlin	Organisation for Economic Co-operation and Development	European trade and policy	Independent/umbrella organisation	Europe/global
Mr	Orlando	IUCN - World Conservation Union	Climate policy	Public body/advise to policy	Europe/global
Ms	Pinborg	European Environment Agency	European environment policy, dissemination	Public body/advise to policy	Europe/Global
Mr	Pritcher	First Renewables, Kelda Group	Renewable energy issues	Private business	UK/Ireland
Dr	Singer	WWF	European climate and energy Policy	NGO	Europe/Global
Mr	Tippmann	Ecosecurities	Forestry energy	Sector consultancy	Europe/Global
Ms	Werner	European Environment Agency	European environment policy, dissemination	Public body/advise to policy	Europe/Global
FORESTRY					
Mr	Angelstam	Grimsö Wildlife Research Station Swedish University of Agricultural Sciences	Forest ecology	Public body/academic	Scandinavia
Mr	Bergmark	IKEA	Wood industry/forest management	Private business	Europe/Global
Mr	Delescailles	European Land Owner association	Forest and agricultural land management	Sectoral representative	Europe
	Fenner	Robinwood	Forest ecology and management	NGO	Europe/Global
Mr	de Galembert	Confederation of European Paper Industries	Wood supply - paper industry issues	Sectoral representative	Europe
Mr	Hakkarainen	Federation of Agricultural Producers and Private Forest Owners (MTK)	Forestry management	Sectoral representative	Scandinavia
Ms	Hufnagl	Conféderation Européenne des Propiétaires Forestiers	Forestry management	Sectoral representative	Europe
Mr	Laine	The Finnish Forest Industries Federation	Forestry industry/forest management	Sectoral representative	Scandinavia
Mr	Melin	TETRA PAK	Wood supply - paper industry issues	Private business	Europe/Global

Mr	PEDERSEN	TETRA PAK	Wood industry/forest management	Private business	Europe/Global
Ms	Pulverer Bergstrand	IKEA	Wood industry/forest management	Private business	Europe/Global
Mr	Rajala	StoraEnso (Joensuu)	Wood industry/forest management	Private business	Scandinavia
Dr	Rois Dias	European Forest Institute	Forest ecology	Public body/academic	Scandinavia
Mr	Vollbrecht	IKEA	Wood industry/forest management	Private business	Europe/Global
INSURANCE					
Mr	Morgensten	Gerling Global General & Reinsurance Co Ltd	Finance - Insurance	Private business	Europe/Global
Mr	Reynolds	Gerling Global General & Reinsurance Co Ltd	Finance - Insurance	Private business	Europe/Global
MOUNTAIN ENVIRONMENTS					
Mr	Bonvin	HYDRO Exploitation SA (Grande Dixence)	Alpine hydroelectricity generation	Private business	Alpine
Mr	Berger	Deutscher Alpenverein e.V.	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
Ms	Doppelbauer	Comité des Organisations Professionelles Agricoles de l'Union Européenne – Comité de la Coopération Agricole de l'Union Européenne	Mountains and tourism	Sectoral representative	Europe
Mr	Götz	CIPRA International	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
Ms	Houillon	HYDRO Exploitation SA (Grande Dixence)	Alpine hydroelectricity generation	Private business	Alpine
Mr	Plassman	Réseau Alpin des Espaces Protégés	Alpine natural park management	Independent/umbrella organisation	Alpine
Dr	Spehn	Global Mountain Biodiversity Assessment, University of Basel	Mountain biodiversity	Public body/academic	Alpine
Mr	Speer	Deutscher Alpenverein e.V.	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
Ms	Streicher	CIPRA Austria	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
Mr	Weissen	Commission Internationale pour la Protection des Alpes	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
Mr	Witty	Deutscher Alpenverein e.V.	Alpine nature protectrion issues	Independent/umbrella organisation	Alpine
TOURISM					
Mr	Baerens	ECEAT Germany	(Eco)tourism issues	Sector consultancy	Germany
Ms	Blangy		(Eco)tourism issues	Sector consultancy	France
Mr	Canova	Associazione Cultura Turismo Ambiente	Sustainable tourism	Sector consultancy	Mediterranean
Ms	Dagmar	Associazione Cultura Turismo Ambiente	Sustainable tourism	Sector consultancy	Mediterranean
Mr	Hamele	Ecostrans	(Eco)tourism issues	Sector consultancy	Germany
Dr	Iwand	TUI	German tourism issues	Private business	Germany
Mr	Kusters	European Centre for Eco Agro Tourism	Agro-tourism issues	Sector consultancy	Europe

Ms	Pirchl	Netzwerk Ländlicher Tourismus, Alpenbüro Netz GmbH	Eco-tourism issues	Sector consultancy	Alpine
Mr	Pils	Friends of Nature International	Eco-tourism issues	Sector consultancy	Germany
Mr	Resh	Global Nature Fund	Eco-tourism issues	Sector consultancy	Germany
Ms	Wheat	Tourism Concern	Sustainable tourism	NGO	UK
Mr	Wilken	Kontor 21	Eco-tourism issues	Sector consultancy	Germany
Mr	Zimmer	Futour GmbH	Eco-tourism issues	Sector consultancy	Germany
WATER					
Dr	Barth	European Commission - The EU Water Initiative	Water management	Public body/advise to policy	Europe/Global
Mr	Crouzet	Institut Français de L'Environnement	Environmental/water monitoring and data	Public body/advise to policy	France
Mr	Havnø	DHI Water & Environment	Water management	Sector consultancy	Europe
Mr	Koch	Office Fédéral des Eaux et de la Géologie (OFEG)	Water monitoring and data needs	Public body/advise to policy	Alpine
Mr	Janeiro	Euroelectrics	Hydroelectricity generation	Private business	Europe
Mr	Preux	Office International de l'Eau (OIE)– Direction de la Documentation et des Données	Water monitoring and data/water management	Independent/umbrella organisation	Europe
Dr.-Ir.	Schädler	Bundesamt für Wasser und Geologie	Water monitoring and data	Public body/advise to policy	Germany
Mr	Victoria	Veolia Water	Water management	Private business	Europe/Global
JOURNALISTS					
Ms	Kerstin	Freelance Journalist	Scientific journalism	Media	Germany
Mr	Kixmüller	Potsdamer Neueste Nachrichten	Scientific journalism	Media	Germany
Dr	Knauer	Freelance Journalist	Scientific journalism	Media	Germany
OTHER IDENTIFIED STAKEHOLDERS					
AGRICULTURE					
Mr	Tompkins	National Union of Farmers (NFU)	Farmers' management practices and needs	Sectoral representative	UK
BIODIVERSITY					
Mr	Debussche	Conservatoire National de Porquerolles	Natural park management	Public body/resource management	Mediterranean
Dr	Pereira dos Santos	Instituto de Conservacao da Natureza	Biodiversity and nature conservation issues	Public body/academic	Mediterranean
Mr	Smit	Eden Project	Biodiversity and nature conservation issues	NGO	UK
Ms	Zahrnt	Bund für Natur- und Umweltschutz Deutschland	Biodiversity and nature conservation issues	NGO	Germany
		Conservatoire National Botanique - Gap Charance	Natural park management	Public body/resource management	Alpine
		Liga para a Protecção da Natureza	Biodiversity and nature conservation issues	NGO	Mediterranean

CARBON STORAGE/POLICY					
Mr	Billings	British Biogen	Biomass energy and commercial outputs	Independent/umbrella organisation	UK
Mr	Fernandez-Galliano	Council of Europe	Environmental policy	Public body/advise to policy	Europe
Dr	Henninger	World Research Institute (WRI)	Biochemistry	Public body/academic	Global
Mr	Hoffmann	Shell Foundation Shell Centre	Environmental issues	Private foundation/business	Global
Dr	Kete	World Research Institute (WRI)	Biochemistry	Public body/academic	Global
Ms	Liljeskjöld	Swedish Environmental Protection Agency	Environmental policy	Public body/advise to policy	Scandinavia
Mr	Nicholson	BP Amoco	Environmental advisor	Private business	Global
Dr	Schlamadinger	Joanneum Research	Biomass energy - climate negotiations	Public body/academic	Europe
Mr	Sjöström	Vattenfall	Energy production	Private business	Europe
Dr	Turnstall	World Research Institute (WRI)	Biochemistry	Public body/academic	Global
Dr	Voigt	European Topic Centre on Air and Climate Change/National Institute for Public Health and Environment	Climate and environmental issues	Public body/advise to policy	Europe
Mr	Wall	European Commission DG Industry	Industrial issues	Public body/advise to policy	Europe
Mr	Zapata Salgado	Secretaría General de Medio Ambiente; Ministerio de medio Ambiente	Environmental policy	Public body/advise to policy	Mediterranean
		Departement de Medi Ambient, Generalitat de Cataluna	Environmental policy	Public body/advise to policy	Mediterranean
		Swedish Ministry of the Environment	Environmental policy	Public body/advise to policy	Scandinavia
		Swedish Environmental Agency	Environmental policy	Public body/advise to policy	Scandinavia
		Jönköping Regional Planning Authority	Land use - environmental policy	Public body/advise to policy	Scandinavia
		Universal Carbon Exchange Limited	Carbon trading	Private business	Global
FORESTRY					
Mr	Bastiaansen	European Confederation of Woodworking Industries	Wood products/forest management	Sectoral representatives	Europe
Mr	Crochet	Confédération Européenne des Propriétaires Forestiers (CEPF)	Forest management	Sectoral representatives	Europe
Dr	Gisch	Féderation Européenne des Communes Forestières (FECF)	Forest management	Sectoral representatives	Europe
Mr	Huart	European Timber Trade Association	Forest management	Sectoral representatives	Europe
Mr	Mateu	Centre de la Propietat Forestal Generalitat de Calalunya	Forest management	Sectoral representatives	Mediterranean
Dr	Meyer	Ministerial Conference on the Protection of Forests in Europe (MCPFE)	Forest management	Public body/advise to policy	Europe

Mr	Paschalis	Union of European Foresters	Forest management	Sectoral representatives	Europe
Mr	Schopfhauser	Confederation of European Paper Industries (CEPI)	Forest management	Sectoral representatives	Europe
Mr	Thivolle-Cazat	'AFOCEL - Laboratoire Economie et Compétitivité	Forest management	Sectoral consultancy	France
		Pan European Forest Certification (PEFC)	Forest management	Independent/umbrella organisation	Europe
		Forest Stewardship Council	Forest management	Public body/advise to policy	Europe/Global
		Swedish National Board of Forestry	Forest management	Public body/advise to policy	Scandinavia
		Pan European Forest Certification (PEFC)	Forest management	Sectoral representatives	Europe
		Forest Stewardship Council	Forest management	Sectoral representatives	Europe
INSURANCE					
Ms	Milne	Association of British Insurers	Finance - Insurance	Sectoral representatives	UK
Ms	Wilke	Swiss Reinsurance Company	Finance - Insurance	Private business	Europe
MOUNTAIN ENVIRONMENTS					
Dr	Lens	Deutscher Alpenverein e.V.	Alpine nature protectrion issues	Public body/academic	Alpine
		International Geosphere Biosphere Programme (IGBP) mountain research Initiative	Alpine ecology	Public body/academic	Alpine
TOURISM					
Mr	Betton	The Association of British Travel Agents (ABTA)	Tourism and tourism operators issues	Sectoral representatives	UK
Prof. Dr	Di Castri	Centre National de la Recherche Scientifique	Tourism issues	Public body/academic	Mediterranean
Ms	Eplar-Wood	The International Ecotourism Society	(Eco)tourism	NGO	Global
Dr	Nash	Robert Gordon University	Tourism issues	Public body/academic	Global
WATER					
	Anhidra	Anhidra, Consultoria Agroambiental	Agricultural water management	Sectoral consultancy	Mediterranean
	Aquaprotec	Aquaprotec	Water management	Sectoral consultancy	Central Europe
Prof.	Berga	UPC – EHMA	Hydrology/water management	Public body/academic	Mediterranean
		Compania General de Sondeos	Water management	Sectoral consultancy	Mediterranean
Ms	Postel	Global Water Policy Project	Water management and policy	Public body/advise to policy	Global
Mr	Proglio	Vivendi / GENERALE DES EAUX	Water management	Private business	Europe/Global
Mr	Tardieu	Vivendi Environment	Water management	Private business	Europe/Global

Annex 5 - Abbreviations

In the following we list and explain some of the more frequently used abbreviations for the convenience of the reader. Typically these abbreviations have been explained also on first appearance in the text by a footnote.

A	Adaptation to global change
a.s.l.	Above sea level
A1f	see SRES
A2	see SRES
AC	Adaptive Capacity
AET	Actual Evapotranspiration
ATEAM	Advanced terrestrial Ecosystem Analysis and Modelling. The acronym of this project.
ATEAM-grid	ATEAM produces spatially explicit results for Europe with a resolution of 10'x10', that is approximately 16x16 km per grid cell.
AVEC	Integrated Assessment of Vulnerable Ecosystems under Global Change, concerted action funded by the EU, contract No. EVK2-2001-00074
B1	see SRES
B2	see SRES
C	Carbon
CD-ROM	Compact disk with read-only memory
CGCM2	A general circulation model used to estimate climate change resulting from greenhouse gas emissions
CO_2	Carbon Dioxide
CRU	Climatic Research Unit, University of East Anglia, Norwich, UK
CSIRO2	A general circulation model used to estimate climate change resulting from greenhouse gas emissions
E	Exposure to global change
EnC	Environmental Classification of Europe
EU	European Union
GCM	General Circulation Model. Model of the climate system that is used to calculate climatic trends from emission scenarios. ATEAM used four GCMs: HadCM3, CSIRO2, CGCM2, PCM.
GIS	Geographical Information System
GPP	Gross Primary Production
HadCM3	A general circulation model used to estimate climate change resulting from greenhouse gas emissions
IPCC	The Intergovernmental Panel on Climate Change
LPJ	The Lund-Potsdam-Jena Dynamic Global Vegetation Model. A model that uses input on climate, land use, soil and atmosphere to calculate vegetation growth.
N	Nitrogen
NEE	Net Ecosystem Exchange. The difference between net primary production and heterotrophic respiration.
NH_y	Reduced Nitrogen Forms
NO_x	Nitrous Oxides
NPP	Net Primary Production. The difference between gross primary production and autotrophic respiration.
NUTS2	Nomenclature des Units Territoriales Statistiques 2: regions or provinces within a country. There are around 500 NUTS2 units, as apposed to only 17 EU countries.
PA	Planned Adaptation
PCM	A general circulation model used to estimate climate change resulting from greenhouse gas emissions

PET	Potential Evapotranspiration
PI	Potential Impact of global change
Rh	Heterotrophic Respiration
RI	Residual Impact of global change
S	Sensitivity to global change
SOC	Soil Organic Carbon. The amount of organic carbon that is contained in the soil of terrestrial ecosystems. The soil accounts for two-thirds of the global terrestrial carbon stocks.
SRES	Special Report on Emission Scenarios. There are four scenario families (A1, A2, B1, B2) representing different future worlds with different greenhouse gas emission trajectories. The A1f is a special scenario within the A1 family, representing a world with intensive fossil fuel use.
V	Vulnerability to global change
WP	Work Package. This project is subdivided into a number of work packages which tackle tasks necessary to achieve the overall objective.