European Climate Change Programme

Working Group II
Impacts and Adaptation

Agriculture and Forestry Sectoral Report

The EU's Adaptation Programme

Adaptation is a new policy area for the European Climate Change Policy. The Impacts and Adaptation Workgroup has been set up as part of European Climate Change Programme (ECCP II). The main objective of the workgroup is to explore options to improve Europe's resilience to Climate Change Impacts, to encourage the integration of climate change adaptation into other policy areas at the European, national and regional level and to define the role of EU-wide policies complementing action by Member States.

The aim of this initial programme of work is to identify good practice in the development of adaptation policy and foster learning from different sectoral experiences and explore a possible EU role in adaptation policies.

The Commission has led a series of 10 sectoral meetings looking at adaptation issues for different sectors. One of these meetings looked at agriculture and forestry in particular. This report summarises the state of play in the agriculture and forestry sector in relation to adaptation to climate change on the basis of the information gathered at the stakeholder meeting[1].

Key Impacts of Climate change on Agriculture and Forestry

The meeting drew out the general expected impacts of climate change across Europe. The existing variations between predictions generated by different models, and according to different time horizons, are an important factor when considering impacts. However, a broad set of expected impacts in climate variables can be described as follows:

- An increase in mean temperature (1-7˚C) by 2100 depending on the region,
- In most regions a higher increase in temperatures in the summer and autumn than the winter and spring,
- Wetter winters and dryer summers, with little change in overall precipitation in North-West Europe,
- Increased variability of winter rainfall in North-West Europe,
- Decrease in average precipitation due in particular to decline in summer rainfall in Southern Europe,
- Increased frequency of hot, dry summers,
- Increased frequency of mild, wet winters,
- Sea level rises in may cause particular problems in some regions,
- Potential increased frequency of extreme events such as hail, storms, heat waves and droughts.

It is important to consider the crop mix and regional location of areas or farms when looking at how these changes will affect agriculture and forestry systems.

Across Europe, the south-east regions and Mediterranean areas are considered the most vulnerable. These changes are likely to have downstream economic and social effects, exacerbated in more sensitive areas where agricultural or forestry activities are already marginal (e.g. Alpine area). They might also bring pressure in northern countries to increase production to compensate for decreases in production elsewhere.

[1] The extensive minutes of this stakeholder meeting can be accessed through the EU European Climate Change Programme II pages at http://ec.europa.eu/environment/climat/eccp_impacts.htm

Agriculture

Changes in mean temperatures, precipitation patterns, increased climate variability and extreme events affect a number of physical and biological processes that intervene in agriculture systems. It is likely that the slightly warmer winters will be the most influential over the longer term. In the short term, the increased frequency of extreme events could be more important than the change in mean climate variables.

In terms of the downstream impacts on agriculture, there is a mix depending on the specific region.

Potential positive impacts:

- more efficient use of water in plants (under elevated CO_2 concentrations),
- CO_2 fertilisation of plants,
- longer growing seasons (Northern Europe),
- new cropping opportunities (Northern Europe),
- some pests and diseases may be reduced.

Potential negative impacts:

- increased water deficit in temperate and semi-arid regions, due to changes in summer precipitations, which may lead to lack of water for irrigation and reduced soil moisture content,
- soil-compaction and cracking in relation to lack of water,
- loss of soil carbon content,
- mineralization of soil carbon due to temperature increase,
- increase of CO_2- and CH_4-emissions from permafrost soils,
- heat stress will affect crop yields and livestock activities (including implications for animal welfare),
- changes in pests and diseases (including animal diseases) requiring, for example, increased pesticides input in Northern areas,
- increased night frost damage,
- sea level rise-related changes in some coastal areas, such as loss of land and salinisation,
- increased short-term natural extremes such as storms and droughts frequency, which may lead to crop damage and soil erosion,
- less cropping opportunities in some regions (Southern Europe).

There is an expectation that the climatic suitability of crops will generally be moving northwards as a result of these impacts. This movement can be attributed to the changes in temperature, changes in rainfall distribution over time and an increased variability in climate patterns in general.

Many regions will face a combination of these potential impacts and adaptive measures will have to be prioritized. However, the degree of uncertainty over the impact of climate change is such that the necessary steps might be unclear and it is likely that more crop failures will be experienced.

Forestry

In terms of forestry, the longevity of trees is an important consideration in understanding the real impacts of these long-term climatic changes. There are also a

range of changes expected to affect the forestry sector. Some suggested impacts are captured in detail in the table in Appendix I provided by the Food and Agriculture Organisation (FAO).

Some of the important impacts to consider overall are:

- changes in productivity, and even viability, of the forests in relation to changes in fertilization patterns or mix of tree species,
- increase in water stress,
- increase in fire risk in terms of frequency and scale of fires,
- increase in nutrient imbalances in soils,
- overall loss in value of forest assets following large-scale disasters,
- susceptibility of forests, especially commercial plantations, to disease and pests,
- impacts on priority species, habitats and Natura sites.

It is expected, as with arable crops, that the favourable climate zones for species will migrate northwards in Europe with the expected climatic changes. The rapid rate of climate change however raises questions about the tracking of the movement of favourable climate zones by trees in the natural and semi-natural situations, and the commercial realization of planted forests able to reach harvestable maturity in some current locations. Some of the most vulnerable species, such as the Norway Spruce in many parts of Europe, may also be the most prevalent in a given area.

In terms of forest systems, these impacts will manifest themselves at various scales, ranging from physiological changes through to ecosystem effects and then to major disruptions or disasters.

Other factors

It is important to note that climate change is only one factor currently affecting these sectors, adding on to other environmental stresses or economic pressures. Other influences include:

- air pollution (such as nitrogen or sulphur deposition),
- water scarcity due to mismanagement or diversion of water or variable water availability,
- competition on the international markets in farm and forestry produce,
- local market conditions,
- prevailing management practices and land-use planning and policies,
- non-farming activities in rural areas,
- environmental policies and other legislation.

These other factors are in some cases currently more important for the vulnerability of agriculture and forestry than climate change impacts alone. However, climate change often is likely to worsen the situation and increase environmental stresses such as the pressure on biodiversity and water resources.

Adaptation options

According to the literature, adaptation refers to practices, policies and projects with the effect of moderating damages and/or realizing opportunities associated with climate change, including climate variability and extremes, and sea level rise.

In the agriculture and forestry sectors several potential adaptation responses have already been well explored. It is also important to note that there is some autonomous adaptive capacity at the regional and in particular at the farm level, triggered already today by weather or climate variability. These autonomous adaptations include, for example decisions regarding infrastructure, irrigation or choice of crops.

Proactive adaptation options have been identified and include:

Arable Land

- changes in breeding programmes to develop better drought and heat resistant varieties,
- plans for more effective use of irrigation. However, in most cases this would accentuate water stress, with climate change-related water shortage adding tension to such an approach, and in many areas water-use for irrigation is already environmentally unsustainable,
- shift away from autumn sowing, where feasible,
- new crops and new management techniques e.g. requiring less water,
- monitor soil changes and develop land management practices to adapt to these changes,
- monitor pests and diseases and develop sustainable farming practice that minimizes susceptibility to pests and diseases e.g. by practicing land rotations and avoiding monocultures,
- minimum tillage techniques,
- changing field design to increase ground cover in some cases, expanded field margins,
- suitable upland farm or land management is important so that upland areas are used to slow run off and reduce peak water flows,
- putting back natural features such as hedgerows to help reduce erosion,
- design of glass houses in a suitable fashion.

It has to be considered that all the potential adaptive measures are not appropriate everywhere and need to be assessed at the appropriate spatial level.

Pasture

- manage winter forage (growth, utilization and water management),
- alter conservation practices for dry summers,
- provide shade for the animals,
- design of animal housing,
- drinking water available for summer pasture,
- compatibility of the breed for grass-clover under warmer, drier conditions,
- use of fodderbanks,
- breeding plans or change in breeds to adapt to changed conditions,
- suitable upland farm or land management to slow run off and reduce peak flows.

Forests

A range of suggested adaptation options for forest management are provided in more detail in Table 3, Annex I. They include:

- species choice and selection, potentially including the use of non-native species, with due regard for biodiversity but with priority given to well adapted local species,
- land-use choices and design of e.g. farms, forests,

- forest management,
- biodiversity – priority habitats & species, Natura sites High Nature Value Forestry systems.

Decisions about options have to be taken with due consideration to the contributions that the agriculture and forestry sector make to the mitigation agenda, and also to other environmental services, such as biodiversity.

Existing/Relevant policies at the EU level

One of the EU's clearest roles in relation to adaptation to climate change in the agriculture and forestry sectors will involve using the existing EU-level policies and measures to their fullest potential and integrate climate change adaptation options into their respective implementation. The EU could also play an important role in communicating climate change impacts and possible adaptation to national Governments by, for example, showcasing good adaptation case studies that deliver for a range of EU objectives.

The relevant EU policies and legislation identified in relation to the agricultural and forestry sectors were:

- Common Agricultural Policy (CAP) including the 2003 review,
- Communication on risk and crisis management in agriculture COM (2005) 74 final, and Report on risk management tools for agriculture[2],
- Rural Development Regulation 1698/2005 and Community Strategic Guidelines for rural development (2007-13),
- The Water Framework Directive (WFD) Directive 2000/60/EC,
- Habitats Directive (92/43/EEC),
- Birds Directive (79/409/EEC),
- Community programme on the conservation, characterisation, collection and utilisation of genetic resources in agriculture (Council Regulation (EC) No 870/2004)[3],
- Report on risk management tools for agriculture[4],
- EU Forestry Action Plan COM (2006) 302 final[5],
- Forest Focus Regulation (2152/2003),
- Thematic strategy on soil protection, and forest fire prevention actions,
- Proposal for a Directive on the assessment and management of floods (COM(2006)15 final of 18.1.2006),
- Proposal for a soil framework Directive.

The rural development policy for the period 2007-13 and the recent CAP reforms already provide the possibility for flexible management in the agricultural context – an important element of adaptive capacity. Although the CAP policy instruments do not explicitly encourage adaptation, Member States can use the measures already in place within the rural development policy to help alleviate climate change impacts on the sector.

[2] http://ec.europa.eu/agriculture/publi/insurance/index_en.htm
[3] http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=32004R0870&model=guicheti
[4] http://ec.europa.eu/agriculture/publi/insurance/index_en.htm
[5] In strict terms, the EU has no competency in forestry policy, but other environmental and rural policy influences forestry.

The Rural Development mechanism provides an excellent framework to deliver adaptation measures in both forestry and agriculture, but it currently receives only a small part of the CAP budget (approximately €11Bn per annum for the EU-25) and is expected to meet a range of EU objectives including biodiversity, water, rural development, competitiveness, etc. If the Rural Development mechanism is to make a genuine contribution to adaptation, it will need a corresponding increase in funds available.

Once adopted, the INSPIRE Directive is considered an important and powerful tool to seek agreement in relation to data sharing – relevant to this agenda, amongst others. This is an EU initiative to establish an infrastructure for spatial information in Europe that will help to make spatial or geographical information more accessible and interoperable for a wide range of purposes supporting sustainable development.[6]

Research

The Seventh Framework Programme for Research includes a wide range of projects related to climate change and agricultural issues. These include research to downscale climate models for more detailed and regional information on climate change impacts, as well as research on land use and projects focusing on improving information exchange and data collection in certain areas (e.g. Global Earth Observation System of Systems (GEOSS)[7], CarboEurope[8]).[9]

The Matisse project will be important at the EU level to include the water dimension in an integrated way, whilst the Harmonica project will be looking at stakeholder perspectives.

The European Flood Alert System (EFAS), launched in 2002[10] is being developed by the Joint Research Centre (JRC) and when complete will provide medium-range flood simulations across Europe with a lead-time between 3 to 10 days.

EFAS should provide the European Commission with useful information for the preparation and management of aid during a flood crisis. The system will also be able to provide medium-range flood information that can help Member States prepare for a future event. The first prototype elements of the EFAS system should be ready in 2006.

GMES (the Global Monitoring for Environment and Security) tool, also under development by the JRC, provides geo-spatial information in relation to security and the environment. GMES is another powerful information tool that should be able to assist with the risk management and preparedness for floods, fires, subsidence, landsides and coastal events. All of these events might affect agriculture and forestry. The GMES system is due to be implemented over the period 2004-8 and it

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[6] Site: http://inspire.jrc.it/home.html

[7] http://www.epa.gov/geoss/index.html, http://ec.europa.eu/research/environment/geo/article_2450_en.htm

[8] Integrated Project CarboEurope-IP, Assessment of the European Terrestrial Carbon Balance. http://www.carboeurope.org/. CarboEurope-IP aims to understand and quantify the present terrestrial carbon balance of Europe and the associated uncertainty at local, regional and continental scale.

[9] A full list of the relevant programmes can be found in the minutes of the ECCPII Impacts and Adaptation Agriculture and forestry meeting on 3 May 2006. This is available on the DG Environment Webpages, under the adaptation topic.

[10] Commission communication (COM(2002)-481)

is therefore relevant that the EU includes GMES in its approach to climate change adaptation.

The European Forest Information System (EFIS) project, also developed by the JRC seeks to compile, process, analyse and disseminate available forestry information of various heterogeneous data sources on international, national and regional levels. This work represents a contribution to the overall EFICS (European Forestry Information and Communication System) programme.

JRC is also involved in other relevant areas, such as the work on drought monitoring models and on forest fires monitoring.

Examples of existing initiatives at Member State level

There is a range of actions currently carried out across EU in relation to adaptation and climate change in the agriculture and forestry sectors. However, there is no comprehensive overview available for all Member States yet. Some examples are provided here:

1. The Dutch government has been looking at the issues related to a surplus of water through three tools:
    a. crop damage payout structure,
    b. environmental services (e.g. designated areas for water storage),
    c. innovations (e.g. floating greenhouses).

2. In the UK, the UK Forestry Commission is developing a range of approaches to incorporate climate change impacts into their forest management. The favoured approaches are chosen as “no regrets” or “low regrets” measures to handle uncertainty in prediction and the longevity of forests. The latter means for example that a young forest has to cope with both current climate and a different future climate;
    a. choice of planting stock through a climate-matching approach,
        i. forest design through broadening age and species distribution, and by using certain species mixtures as well as creating larger areas of better connected woodlands,
    b. management of existing forests in order to improve the capacity of the woodland to adapt to climate change.

    In the UK a long running programme funded by the Department for the Environment, Food and Rural Affairs (Defra) on the prediction of impacts and adaptation in agriculture ended in 2005/06. Current research is looking at the impacts of extreme events on UK agriculture, particularly on crops, and on the impacts of climate change on the effect of current agri-environment scheme interventions. A significant research project to facilitate the transfer of technologies from relevant climatic zones was started in 2006.

    In Wales, the Spatial Plan on Land Use Visions is addressing issues of upland land management to reduce the impacts of extreme precipitation events.

3. In Denmark, a “nature-based forest management” approach is being taken, which includes climate change elements and therefore increasing the species and age mix in the forests, putting the emphasis on the reintroduction of native species and the reestablishment of a more natural forest structure, but also experimenting with non-native species. This process includes a high

degree of stakeholder engagement and consultation and has been named "Adaptive Collaborative Management". This approach demonstrates a willingness to avoid the use of master plans and top-down visions and introduces a more integrated landscape system. The work also included calculations of the costs and returns of these approaches (forestry economics).

4. In Sweden Skogforsk (The Forestry Research Institute of Sweden) devised a new strategy for the breeding of pine, spruce, birch and contorta pine in the early 1990s. In this strategy, which is still applied, account was taken of expected climate change in order to ensure long-term dynamic preservation of genes, to create a state of readiness for future climate change and to improve the general characteristics of the trees in terms of vitality, growth and timber quality. In practice, this activity entails working on a number of breeding populations for different climatic conditions (temperature sum and light conditions). These cover existing climate zones in present-day Sweden and in a changed climate. This has created a readiness for measures in planting new forest stands when this is judged relevant

5. The NEWAL-NET project in Germany is a sustainable forestry project that includes consideration of climate change elements in land-use decisions.

Gaps identified

Areas where further work is needed to enhance development of adaptive measures have been identified, although this could be at the local, regional, national or EU level. Some views among stakeholders are that a more thorough analysis of climate change and its expected impacts on agriculture and forestry needs to be undertaken to underscore robust proposals and strategies for adaptation in these two important sectors, although it must be stressed that this should not be a deterrent for delaying action.

Specific activities have been organized into four categories: information and knowledge, planning processes, economic stimuli, and risk and disaster management and are identified in the subsequent paragraphs.

Information and Knowledge

- dissemination of information already available on coping with climatic variability and climate change; so far there is no comprehensive overview available for all Member States,
- achieving greater spatial resolution of climate change impacts assessment,
- carrying out further research on:
    - crop and forest yield under climate change scenarios,
    - pests and diseases in crops,
    - effects of extreme events such as forest fires both on agriculture and forestry directly and on the market for agricultural and forestry products,
    - the extent of natural adaptive capacity in the gene pool and through other mechanisms,
    - adaptation impacts on biodiversity – priority species & habitats; Natura sites.
- ensuring consistency in long-term monitoring and data sets to detect changes, by implementing the INSPIRE Directive in a way that ensures the sharing of and public access to environmental information,

- developing monitoring tools for drought sensitivity and other indicators of vulnerability to climate change impacts,
- improving communication between countries or regions on different potential adaptive responses,
- transferring knowledge on adaptation from developing to developed countries,
- identifying tools to engage all of the appropriate stakeholders for two-way dialogues,
- including climate change into training programmes for advisory services in both agriculture and forestry and for farmers and foresters,
- ensuring that any afforestation (e.g. that funded under Rural Development) is carried out with the expected climate changes in mind, so that prudent choices are made with regard to species, location, etc.

Policy planning process

- consider the time dimension of the expected impacts to help set up priorities in the agriculture and forestry sectors,
- take into account that the adaptive actions potentially recommended must be sustainable from economic, social and other environmental perspectives ("*No regret*" measures). No-regret actions are those which have benefits today and increase adaptive capacity,
- understanding how to achieve a more integrated approach to land management that would take into account adaptation and mitigation needs at the same time,
- understanding the potential and limitations of existing policy instruments, in particular the CAP, for agriculture and forestry. This may also help minimize the impacts of climate change in other sectors (e.g. water; soil; flood and fire risk; biodiversity). It is important to note that EU and Member State forestry policies are for sustainable multi-benefit forest management which includes biodiversity.

Economic stimuli

- assessing the financial costs of inaction, co-benefits as well as different mitigation and adaptation approaches as important steps in developing any economic tools or approaches,
- policy incentives for measures addressing climate risks,
- working with insurance companies to develop a common strategy for adaptation to climate change and the agriculture and forestry sector.

Risk and disaster management

- further developing risk management tools and their application,

Opportunities for the EU level

Through the work of the stakeholder group, both gaps and opportunities were identified. Those which are of relevance for the EU in particular are highlighted below, divided again into the same four sections as for gaps

Information and Knowledge

a) the EU could set up a reporting and monitoring scheme on adaptation activities to provide a comprehensive overview for all Member States,
b) the EU could play a role in harmonising some of the assessment work in order to help monitoring across the EU including monitoring the impacts of changes in farming practices,

c) the EU could helpfully contribute to a gap analysis to isolate areas where information is lacking, or research is needed both on impacts and on monitoring of impacts and adaptive actions,
d) the potential need for further work on meteorological information should be assessed (e.g. improved weekly, seasonal and decadal forecast of weather and climate),
e) the EU should also ensure that EU-level research is collated in the field of adaptation and is properly disseminated to inform decisions and actions at both the EU and national level,
f) the EU could assist by providing the means of sharing tools and experience between countries. In particular, discussions about crops and crop systems between countries where a similar change in climate patterns is expected in the future could be promoted,
g) the EU could help support Member States in communication and explanation to stakeholders, the public, farmers and foresters, who carry out the adaptive actions on the ground, which is of great importance,
h) the EU could help in facilitating knowledge transfer mechanisms between all the appropriate players from different fields, e.g. agriculture and the environment,
i) ensure co-ordinated work between different Commission services (as DG Agriculture and Rural Development, Environment, Enterprise and Industry and Research) to deliver shared messages on the challenge climate change poses to agriculture and forestry, and the role of land managers in responding to that challenge, and to ensure that work on climate change adaptation exploits synergies with other areas of EU activity, such as water quality and biodiversity conservation, contributes to goals in these areas where possible, and does not conflict with them under any circumstance,
j) in assessing EU-funded instruments such as Rural Development or Structural Fund Programmes or proposals, the Commission should remind Member States of the need to take adaptation needs into account.

Policy planning process

k) the EU should look holistically at farm and forestry sectors and consider the whole range of pressures and demands that drive their development, including long-term trends,
l) the EU could have a role in improving the understanding of the impact of climate change on global markets for these sectors (both supply and demand) including factors such as food production, consumption patterns, the influence of other demands such as biomass for energy, etc.,
m) the EU could also help to achieve a proper balance between efforts to mitigate climate change and to adapt to its expected adverse consequences,
n) the EU should strengthen its enforcement capacities as better implementation of the existing environmental aquis (most notably the Birds and Habitats Directives, and Water Framework Directive) is a key condition for successful adaptation without negative side effects,
o) the EU should work to try to avoid mal-adaptation and to raise awareness of the importance of this consideration,
p) the EU should explore and evaluate critically the potential role of sectoral policies such as the CAP. Priority actions for further adjustment should be identified,
q) the EU should integrate the approach of different relevant policies across sectors, especially water policy with agriculture and forestry policies as well as nature and biodiversity,
r) the EU should also consider its sphere of influence in relation to land management decisions, which are relevant for adaptive actions,
s) the EU could also have a role in addressing cross-border landscape management issues,

t) awareness should be raised at all levels, including EU and Member State levels, about the possibilities for using certain existing policy frameworks, such as the rural development plans, to help tackle the climate change adaptation challenge.

Economic Stimuli

u) financial levers already exist through the CAP (rural development policy) that could lend support to adaptive actions at farm-level. It is important that the EU assesses whether these need to be strengthened, and makes Member States aware of these possibilities. The EU must also use the opportunity of the 2008 budget review to redirect spending to more environmentally sound farming,

v) it could be explored whether certain types of funding ought to be made conditional on taking adaptive action, such as the ability for individuals or organizations to seek compensation for certain climatic disasters or changes, structural funds and CAP payments. In some cases, this might also be linked to actions such as taking out insurance.

Risk and Disaster management

w) the EU could help develop common tools, including those related to a risk-management approach, for foresters and farmers both in terms of assessments and management of climate change risks,

x) the EU could help co-ordinate work to assess vulnerability to climate change impacts and assess risks for different agro-ecologic areas,

y) the EU might have a role to play in assessing climate change risks across Europe in order to isolate the greatest disaster risk,

z) the EU can also help to ensure that the appropriate indicators of climate change, justified by the most advanced science available are taken as the guiding stimulus in the approach to adaptation policy.

Actions relevant at national, regional and local level

The main concrete adaptive actions in relation to agriculture and forestry will be taken at national, sub-national and local levels. The EU does have a role to play in encouraging the appropriate type of decision-making and management.

In terms of decisions about adaptive actions, a balance needs to be found between top-down planning at the national level and bottom-up stakeholder led action, but it is not the role of the EU to define the proper balance between these approaches.

Local level stakeholders will have the capacity and experience to manage short-term climatic changes but there is a role for joined up thinking to the regional, national and EU-level in relation to the longer-term changes.

Further references and weblinks

http://www.met-office.gov.uk

Appendix 1: Further information on Forestry,
provided by the Food and Agriculture Organisation (FAO)

Table 1: Some aspects of climate change affecting forest trees		
Factor	**Element**	**impact**
Radiation	amount and kind of sunlight	seedling survival, tree morphology, leave morphology, epicormic branching, bark thickness, understory vegetation
Temperature	Annual mean	range, elevation, productivity, competitive strength. Transpiration and water stress
	mean during summer	
	mean during vegetation period	photosynthesis and respiration, productivity, phenology; fruiting and masting
	mean during winter	range, elevation, chilling requirements, cold hardiness, seed germination, assimilation in winter, pest/disease survival
	temperature zones	natural range, elevation, migration
	annual maximum	drought, sunscald; seedling mortality; fruiting
	annual minimum	frost cracks; bark damage, pathological heartwood, survival of exotics and of invasive species, germination
	temperature day sums	phenology, flowering, fruiting, distribution
	sequence freezing-thawing	frost heaving of seedlings, tree dieback, top dying
	soil freezing	water uptake, frost dryness
	permafrost	stability, rooting depth
	spring frost	shoot and foliage dieback, seedling kill, distribution
	late season frost	frost damage to second flush; distribution
Precipitation	mean annual	water stress, productivity, resilience against attack, range, altitude, interceotion, stemflow, throughfall
	mean vegetation period	
	mean winter	
	dew formation	water stress
	relative humidity and vapour pressure deficit	transpiration, water stress, productivity
	extremes	drought, waterlogging and oxygen uptake, windthrow
	soil moisture recharge	water stress, productivity, distribution
	waterlogging of soils	wind-throw, lack of aeration
	water stress / drought	productivity, susceptibility to damaging agents, wood density, regeneration, masting, dieback, stem cracks, rooting habitus, seedling survival
	length of snow cover	frost protection, water stress, fungus on seedlings, damage by rodents, snow break, stemform
	maximum snow depth	
	duration	
	snow-rain proportion	
	cloud cover	water balance, frost damage, water stress, photosynthesis, aerial uptake of water, cloud forest survival
	fog days	water balance, aerial uptake of water
	hail	bark and terminal shoot damage, seedling survival
	wet snow	breakage, distorted growth, wood properties

	freezing rain	
Wind	mean - summer-winter	breakage, blow-down, wind checks, twig breakage, foliage loss, wind sheer, maximal age, wood properties
	maximum wind speed	
	storm frequency	
	seasonality	
	Downbursts	

Table 2: Some aspects of climate change affecting forest ecosystems		
Aspect	Impact	Comment
ecosystem	productivity	even if Net Primary Productivity is enhanced or changed, Net Ecosystem Productivity, biomass and carbon sequestration might not be
	composition	living and non-living components have different sensitivities and vulnerabilities and countless interactions; predictions difficult; invasion by new and exotic species; possible loss of old-growth forests
	extent and distribution	change as a function of climatic variables, sensitivities, migration capacities, competitive strength, synergies
	regeneration	particularly vulnerable stage; effects likely; possibly changes in succession
	natural mortality	likely to increase due to changed growth and competition, extreme events
	ground vegetation	increased nutrient availability in the top soil may enhance competition; possibly enhanced acidification in podzolic soils
	extinction	key species might not be able to adapt or migrate
existing stress	ozone, acid rain, game, drought	existing stresses interact with climate change in multiple, often negative ways
site	nutrients, water, soil organic matter	altered productivity; breakdown of organic matter affected; possible increased (e.g. N) or reduced (micronutrients) availability; toxicities (Mn, AL in acid buffering), more acidification and podzolisation; distorted growth
	new wetlands	as a consequence of more rain and impeded drainage
	permafrost	formation of thermo-karst, mortality of some tree species
disturbance	fire frequency, severity, extent	regional differences, but overall more severe impact; might hasten autonomous adaptation of ecosystems to new fire regime
	blowdown, storm damages	no firm forecasts and different for regions; intensity will increase in many areas; serious threat to forest management; effect on age class distribution, net revenues
	insects, fungi, pathogens	overall much more severe impact, spread to new regions; new species, enhanced by stressed forests; nutritional quality of foliage reduced; some pests and diseases might decline
	mammals, rodents, birds	denser population, changed ranges, feeding habits, behaviour
	interactions	typically, forests succumb to multiple interactions of damaging agents
services	wood	during transition phase enhanced supply from salvage; regional increases, decreases, globally slight increase in long term supply; price changes; species and size of timber likely to change strongly; quality affected, e.g. basic wood density, knots, form
	effect of logging	risk of soil compaction increased with more winter rain, less snow cover

	fuel-wood	increased demand for sustainable bio energy
	water	runoff likely to decrease in summer and increase in winter; species may react differently
	scenic, recreation	likely to suffer from disturbances; changing climate will change patterns and location of recreational visits
	income	likely to increase regionally; enhanced productivity likely to be offset by increased risk; overall income function likely to be reduced; market disturbances likely, salvage logging increases
	conservation, biodiversity	need management practices adapted to climate change; biodiversity impacts with possible positive and more commonly negative effects
forest sector, industry	raw material supply; importance of sector professional employment	major upsets, drastic changes and decline likely in many regions

Table 3: technical options for adaptive management of forests	
Phase	**Measure**
Regeneration	adjust silvicultural system and/or regeneration technique
	prefer mixed stands
	match species and provenance to present and future site and climate
	consider introduction of proven species
	adapt natural regeneration to changing reproduction and competition patterns
	rehabilitate degraded and eliminate off-site stands
	consider nurse trees
	consider artificial shading in planting dry, exposed sites
	adjust planting densities
	monitor competing vegetation
	add nutrients likely to become deficient
	under-plant high risk stands
	treat for wind resistance starting systematically from establishment
	monitor effect of game and rodent populations
tending of stands	adjust intensity and frequency of pre-commercial thinnings and stocking control
	adjust stand structure and composition
	phase out off-site stands
	enhance monitoring for pathogens and insects
harvesting	avoid large clearcuts, edge effects, fragmentation
	adjust harvest method and equipment, reduce impact of skidding
	consider converting to uneven-aged stands
protecting forests	intensify monitoring of risk and damage
	eliminate added stresses (acid rain, game)
	adjust fire management; use fire-smart landscapes
	protect rare habitats and species, genetic stocks; all semi natural and natural habitat
management, planning, and administration	raise awareness and information of top and field staff, owners
	educate extension foresters
	rewrite silvicultural and management guidelines
	intensify or update site classification and mapping
	provide adequate human resources; management and labour intensity likely to increase
	plan and train for calamities and timber salvage, sales pools
	integrate climate change into management plans
	reconsider rotations and allowable cut
	reconsider species choice and introduced species
	update yield tables
	carry out professional national and local vulnerability analysis
	prioritize no-regret options
	practice adaptive forest management
	monitor for climate change impacts in protected areas