Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A review of science, policies, and practices

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Technical sessions - summary reports

Session 1. Physiological responses of trees to climate

Summary report

Participants considered a number of recent changes in forest ecosystems and discussed whether they could be attributed to climate change. They considered the following evidence in particular.

- The European droughts of 1976 and 2003 gave the opportunity to investigate some aspects of temperate tree response. Some forest tree species that were studied, such as common oak, appeared to be more resilient to drought impacts along an environmental gradient than others, such as Norway spruce, which had the highest negative growth response and recovered slowest. Beech showed a good stress tolerance after one year of drought and, albeit not considering root production maintained net growth through a loss of trunk wood and an elevated fructification. Compared to other tree species, annual mortality of beech was rare.
- In a review of papers published over the last 20 years, 30 papers describe the responses of wood properties in woody species. Most papers agree that increased carbon dioxide increases stem wood production and affects wood chemical composition, particularly increases in soluble carbohydrates. Wood cell structure experienced only minor changes. The combined effect of CO_2 and O_3 was noted to result in increased stem production in aspen. The effects of elevated temperature on wood properties were noted to be the least explored.
- Forest herbs along a latitude gradient found accumulated temperature explained much of the variation in seed production and viability. Results demonstrate that the impact of climate warming on the sexual reproductive traits of forest herbs will be most positive for spring blooming plants and negative for late summer blooming species.

Participants discussed the future impacts of climate change on forests, people and institutions and noted the following.

- Decreasing snow cover and increasing winter temperatures impact fine root dynamics though (mild) drought and frost. In the short term, fine root mortality is compensated for the root loss. Increased C and N will increase the carbon sink strength of Norway spruce fine root systems.
- Some tree species may be physiologically able to cope better with climate change stressors than others. Spruce for example may not cope and adapt on sites where it is introduced whereas native spruce sites may not be as much at risk.
- Climate change is expected to extend growing seasons. As a result the net primary production in temperate and boreal forests is likely to respond with increased photosynthesis. Increased production may net increase economics for tree harvest.

Some possible adaptation measures or management actions, including institutional change, identified by session participants included the following.

- Adaptive forest management may design dispersal corridors, assist migration to improve recruitment of herbaceous plants vulnerable to decreased reproduction when climate warms.
- A strong positive correlation between leaf area to sapwood area ratio and water availability has been observed for several different tree species worldwide. In the jarrah forest of Australia a significant decrease in leaf area to sapwood area ratio may show the jarrah forest ecosystem adapts

to water stress by decreasing their leaf area relative to their sapwood area. Reduction in leaf area relative to sapwood area is an important adaptation for dry forests.

- Earlier greening of some tree species may put them at risk to frost damage.
- Soil temperature increases may speed up mineralization which affects nutrient availability related to increased production.

Participants noted the importance of including basic physiological indicators or variables into forest monitoring and assessment. An example would be leaf area: sapwood ratio as a way to indicate physiological stresses that could be moderated with management change. An expert panel of scientists could be formed to create a short list of indicators.

Session 2. Climate-induced changes in forest ecosystems

Summary report

Many examples of forest changes from all over the world have been reported, primarily changes in vegetation distribution have been reported. In most cases there are some cases that are related to climate. However, many changes can be due to natural causes. It is often wise to adjust or adapt forestry towards the natural vegetation. We cannot produce proof for climate change but undoubtedly there are many examples of changing vegetation occurring, most typically southern species moving northwards (Northern Hemisphere). Several important changes in ecosystems cannot be detected until after a disturbance. Most knowledge comes from the Northern Hemisphere and most studies cover just a few species changes the past 20 years. Few take into account the function of the entire ecosystem. It is important to include humans in the ecosystem.

In the eastern United States actual tree species migration was studied based on forest inventory data. It has been hypothesized that migration should manifest itself first through higher establishment, biomass and survival of seedlings in more suitable climate. In the study, the outcome from new inventory was compared with distribution maps from 1971. Both northern and southern species tended to move northward, but some southern species actually moved south. Data comparability limits firm conclusions.

The future impacts of climate change on forests were considered. Presentations covered models to predict vulnerability and migration and carbon storage effects. Many models were not realistic, for example studying the effect on carbon storage without including harvest regime, age classes or disturbances. There are very little possibilities to check model assumptions and therefore only widely established, published models should be accepted.

In Canada actual land cover changes did lag behind model predictions because older stands persist on site even under worsening conditions and a disturbance is needed for changes to materialize. Receding edge of a forest reacts slower than advancing edge.

In Costa Rica, corridors for species migration were evaluated by modelling. It appears that some of the corridors were badly needed to maintain ecosystems; others did not have much effect. Without effective corridors protected areas will lose much of their value.

Pinus cembra in the Alps faces considerable impacts from climate change. Vulnerability for *P. cembra* was higher outside its fitted climax area. Current distribution map was compared to a future map 2100 modelled using 20 bioclimatic, 6 geomorphological and 6 soil variables. *Pinus cembra* was currently robust in 16 percent of the Alpine area. In the future an upward shift was predicted and only 4 percent is stable area. *Pinus cembra* will be an endangered species if climate scenarios come true.

Isolated Chilean forests depend on fog as a main water source; precipitation is apparently not important. Any negative change in fog frequency would eliminate these forests.

The future impacts of climate change on people and institutions is rarely dealt with and often only superficially. An example of a future impact is the effect of fire, grazing and wood-cutting on social services of forests in Africa. It is unrealistic to eliminate these practices, for example in CDM projects, and some level of these practices is acceptable even for CDM projects. There might have to be tradeoffs in carbon sequestration services against environmental and social services of CDM projects.

The participants discussed potential adaptation measures and identified the following options. Establishing or improving forest monitoring systems will be essential to detect changes and react with adaptation measures; current trend in reducing on-the ground monitoring should be reversed.

Very often, modellers are satisfied by predicting species shift or vulnerability, but do not draw conclusions for adaptation or management and policy change. For example, if *Pinus cembra* in the Alps will drastically recede, what are the effects on erosion, water, avalanches, carbon storage, wood production, social and economic functions? What should be done to adapt now to anticipated effects?

Participants noted the following policy options to most effectively support adaptation of forests and the forest sector to climate change.

- In order to limit the illegal deforestation, all wood products should be certified. Based on the presentation from Costa Rica, consumers benefiting of water from key ecosystems may pay for its conservation. Forests are not always for timber production.
- Coordination by ministries in developing countries for negotiations is not effective. Frequently, the negotiators are non-foresters and have not been adequately briefed on the effects of climate change in the forest sector. Improvement would be needed for post Kyoto regime.
- To enable more sustainable forestry there is a need to create new institutions, especially in developing countries.
- It was stated that the internal information within nations does not always function. A problem is that foresters (agricultural expertise) have little chance to make their voices heard to those who represent the nation (especially smaller nations) in meetings about international conventions.

Session 3. Impacts of altered regimes of extreme abiotic events

Summary report

Participants considered a number of recent changes in forest ecosystems and discussed whether they could be attributed to climate change. They considered the following evidence in particular.

- Temperate and boreal forests subject to increasing temperatures (less snow and permafrost) and greater incidence of extreme weather events (droughts, increased precipitation/floods, higher temperatures, high winds, snow storms) that impact forests by greater incidence and impact of fires, windfall and landslides, that cause changes in species composition and associations in forests that can cause predisposition to other biotic events (insects, diseases and other pests).
- The impacts of climate change on forests will differ by forest type and region. The tropical dry forest ecosystem in southern India, discussed in the session, showed that they are impacted by droughts and high temperatures which can cause delayed mortality depending upon the species, diameter classes, severity of the extreme weather event and other pests. In the African savannah ecosystem in Cote d'Ivoire, earlier dry seasons are bringing about changes in fire use resulting in less intense fires which in turn results in a shift from grasslands to wooded lands. In Mongolia there has been a 4 million ha loss of forests during the last century, caused by a combination of climate change, extreme weather events, fire, insects and diseases and unsustainable land-use practices, including animal grazing, illegal logging and illegal migration. Historical indicators showed an increase in forest fires following years of decreased precipitation. Indicators of a decrease in the incidence of forest fires were correlated with a 16th century Mongolian King's decision to manage a forested area. In Korea, the very young nature of the forests makes it difficult to separate effects of climate change from changes associated with natural succession. In central Europe, there are now more dead trees (mostly caused by drought) than at the peak of the period associated with «Waldsterben» (forest decline).
- Decline in mangroves which is possibly related to the changes in the salinity of the water could be due to a decrease in the in flow of fresh water by decreased precipitation or the increase in the addition of salt water caused by an increase in the number of hurricanes. Correlation is not easy to determine.
- Effects of a combination of extreme weather conditions and possible changes in climatic trends are complexly linked (i.e. increased wind with or without increased temperatures)
- There is a complex link between abiotic and biotic events but they are difficult to disassociate.

Session participants noted the following when discussing the possible future impacts of climate change on forests.

- Correlating longer term climate change and the incidence and impact of extreme weather events on fire, windfall, floods, landslides etc. that impact forests and forest management, are difficult to predict
- Increased frequency of events like hurricanes may decrease the resilience of forests to recover and may in fact have impacts on regenerative species and the distribution of biomass.
- Climatic changes may expose some ecosystems to new risks that they are not well adapted for.

- The diversity of both the species in a forest and the management practices used to manage the forest will all have varying effects on the forest thus making it harder to predict future outcomes.
- Some of these changes might have an affect on the operational aspects of harvesting, such as less frost decreasing access to forested areas and not enabling equipment to be moved.

The future impacts of climate change on people and institutions were discussed and the following points were noted.

- The majority of speakers highlighted the greater incidence and impact of fires and the resulting change in seasons that these fires create in forest, savannah and grassland ecosystems exacerbated by extreme weather events (drought, higher temperatures and wind) that impact the lives and livelihoods of communities.
- The relationships between people, forests and climate change are very complex and the impacts on people and institutions are difficult to model or predict in future scenarios, but in a Central American study there is anticipated to be less high fire risk areas and more moderate fires risk areas (this includes climate and socio-economic and behavioural changes).
- There was insufficient past research in assessing climate change and extreme weather events to predict future impacts on people and institutions with confidence.
- The human adaptation to changing seasons is that fires are being used by different land-users at different seasons for different reasons, with a change in advocacy of burns.
- The point was made that greater variation in weather events is expected. Coping with this will increase the costs of forest management, and traditional means of costing forestry projects may become inappropriate.
- Questions were asked about the reality of predicting the future impacts and how much would be attributed to climate change.

In considering adaptation measures, participants noted the forest management risk assessment needs to recognize instances where: response options are not necessary; management response to the risk is worthwhile; and a management response option is not possible. There may be a need to explore more diverse harvesting regimes including selective logging and encourage breeders to select for other factors than fast growth. Participants also suggested that forest managers not plant monocultures.

Session participants noted that more investment in forest research in developing countries is needed as many adaptation options are hindered by a lack of knowledge. It was noted that it must be recognized that polices must vary for different conditions, such as natural forests vs. planted and managed forests. It was also noted that local peoples must be involved in any policy-making process as they will be the ones ultimately impacted by such policies. Global policies may be needed to support the forests of the world particularly in developing countries where resources are more difficult to obtain.

Session 4. Impacts of climate change on forest growth

Summary report

Scientists must go from giving correct answers to approximate problems, to giving approximate answers to the correct problems. (Dieter Schoene, keynote speech)

Participants noted the following examples of current changes in forests and the forest sector which could be attributed to climate change.

- A reduction in insect diversity as generalist species are favoured to the detriment of specialists.
- Extreme events (e.g. drought) producing lag responses in tree growth, with the importance of the effect growing more rapidly than the importance of the stress (non-linearity of the effect).
- Apparent impact on the health and degradation of freshwater coastal forest swamps in the US resulting from salt water intrusion following drought and storm surges.

It was noted that there are importance differences in how different species react to climate stressors, and the differences among species can vary with stand age and other factors. Such differential responses appear difficult to predict without relatively local knowledge.

The expected future impacts of climate change on forests were discussed by the session participants. Based on the presentations and subsequent discussions the following items were noted.

- Under the IPCC climate change scenarios A2 and A1b, beech and oak are predicted to react differently to climate change in northern France, with both increasing in growth, but with oak being advantaged over beech.
- Instability in climate (e.g. transition to a new steady state) will lead to a decrease in insect diversity, towards fewer specialists and more generalists.
- The total impact of stressors on forest growth and productivity increases faster than the severity of the stressor (non-linear response). These non-linearities must be incorporated into models predicting the impact of climate change on growth.
- In New Zealand weed competition may have a large negative impact on *Pinus radiata* growth in areas with water limitation. Growth of *P. radiata* is very susceptible to modes drop in water availability (problems start with water availabilities dropping <70 percent). Increased temperatures and CO_2 concentrations are expected to result in positive change in forest productivity in New Zealand. However risk factors, such as weeds, pests, and diseases, may counterbalance the forest growth in the country.
- Medium and longer term impacts of pests on forest carbon have received limited attention. This should be considered when assessing the role of forests in carbon sequestration.
- There is no generalized response of forests to climate change; responses differ between regions, as a function of predicted climate scenarios, and between species. For example, *Pinus pinaster* is predicted to have decreased growth in Spain, but the decrease will be greater in areas with greater projected drought. Beech and oaks are predicted to increase in growth in northern France, but beech might be negatively impacted by climate change in Austria. Impacts will be regional.

- There is a need to estimate the impact of cascading systems, i.e. how insect range and defoliation will be impacted by climate change and how this will affect the growth of trees.
- The effects of climate change on forests will happen through extreme events that, by definition, are not common. Effort must therefore be put into extending databases and developing empirical knowledge on extreme events.
- There is a lack of information on the growth of tropical forests, and how climate change will affect that growth.

In considering the future impacts of climate change on people and institutions the participants pointed out that invasive species and expanding populations of native pests have large potential impacts and increasing vulnerabilities of economic systems.

A number of potential management responses and actions were identified by the participants. It was stressed that any forest management plan must incorporate explicitly uncertainty, either through an adaptive framework of periodic plan revision (e.g. every 10 years), or a probabilistic approach where risk and uncertainty are factored in at the outset. The development of international trade standards and increased pest surveillance in response to the threat of invasive species were recommended.

Since many of the predictions regarding climate change and its impacts are known with a great degree of certainty (i.e. very large convergence of climate models), participants noted that it is possible to start now in devising solutions and adaptation plans. For example, Mediterranean countries such as Spain will see a dramatic reduction in productivity of main tree species (*P. pinaster*). In this case it would be possible to perform a socio-economic analysis of forest cover loss and devise adaptation plans such as planting other vegetation types to maintain ecological services.

It was noted that adaptation will be best supported when there is a translation of results from process or empirical models into economic and social terms. Approaches like those used in the field of climate modelling may be useful examples.

Participants considered the policies needed to support the adaptation of forests and the forest sector to climate change. They reiterated comments by Dieter Schoene in his keynote speech that we must not count only on autonomous adaptation, but develop planned adaptation measures that may incorporate awareness building in professional and local communities, monitoring of particularly vulnerable areas as test sites, etc. They noted that such an approach needs to be implemented in addition to the usual arsenal of "autonomous" adaptation measures. Participants also made the following conclusions in relation to policy and research needs.

- Policy decisions need to accept flexibility and uncertainty. There is a need to increase the flexibility and diversity of forests in order to make them more robust and resistant; however the most diverse ecosystems are not necessarily the most stable and resilient ones. It is not clear what type of forest is best suited to future conditions (e.g. more diverse versus less diverse forests), and hence it is difficult to develop adaptation policies, as biological systems are inherently complex, and this complexity is compounded by the long-lived nature of the trees. This likely explains the paucity of information on adaptation policies.

- There is a need in research in tropics; conservation of tropical forests should be a priority. The Center for International Forestry Research (CIFOR) has established plots in tropical forests worldwide in Asia, Africa and Latin America. Global efforts are needed to model tropical forest conditions and provide likely scenarios for forest policy.
- Process-based models predict future conditions based on current conditions in different climatic zones. These models should include excess of CO_2, more frequent extreme climate events, etc. Models are available to forecast future probable situations under specific situations, but are still very much limited in scope. Using meta-modelling approaches, as used by the Intergovernmental Panel on Climate Change (IPCC), to provide information on future scenarios relevant for policy-making could be useful.

Session 5. Forest health: effects of air pollution, forest pests and pathogens

Summary report

Participants noted a variety of recent impacts on forest ecosystems that could be attributed to climate change.

- Ozone pollution continues to pose a significant threat in the Northern Hemisphere. Important abiotic forests stressors include increasing concentrations of tropospheric ozone and carbon dioxide and elevated levels of atmospheric nitrogen deposition. Increased ozone concentrations and nitrogen deposition disrupt the ratio of above and below ground biomass leading to increased susceptibility to drought thereby accelerating drought stress and exposing forests to increased insect outbreaks and wildfire.
- In Europe, data on deposition of sulphate, nitrate, and ammonium of the years 2000-2005 show marked spatial patterns and temporal trends. Sulphate has decreased in monitoring plots but sulphate, nitrate and ammonium deposition were found to still exceed critical loads at many forest sites.
- Climate change can affect forest pests and the damage they cause by: impacting their development, survival, reproduction and spread; altering host defences and susceptibility; and indirectly impacting ecological relationships such as changing the abundance of competitors, parasites and predators. A shift in geographic range (higher altitudes and latitudes) is being observed for many forest insects. Some insect emergence occur earlier in the spring and last longer.
- Increasing susceptibility of trees and forests to pathogens and insects because of climate change are present and expected to continue. In several papers, including ones presented by FAO and IUFRO Division 7, the current forest health changes caused by interactive effects of combination of stressors in various geographic areas as well as projections of the future expected changes in forest health have been compiled.
- In North America, forest fragmentation continues to affect forest health and function. Insect impacts in Canada are increasing. Aspen defoliators, gypsy moth, spruce budworm, and mountain pine beetle are all increasing in Canada. The current outbreak of the mountain pine beetle (*Dendroctonus ponderosae*) in British Columbia is the largest ever recorded. The epidemic has been attributed to a large expanse of even aged single species forest which has been exacerbated by fire protection practices and climate. Logging of pine of this general area is relatively recent. Even though many trees are killed, lodgepole pine continues to dominate the area and ¾ of stands attacked by the beetle usually does not need to be replanted. Logging and replanting in older age classes of trees may be reasonable but not for younger stands where merchantable wood is slight. Doing nothing for some age classes is often the best management practice.
- A variety of exotic invasive insects are increasing in Mexico. Lodgepole pine forests in the interior western US are severely infested by mountain pine beetle at higher elevations than expected. Favourable winter conditions are increasing insect outbreaks. Gypsy moth and other invasive species are continuing to spread into previously uninfested forests throughout the eastern US. *Phytophthora ramorum* is killing trees in California and Oregon but mortality is not apparent outside of those states.
- Recently, *Ips typographus* can realize two years of life cycle in one year in Poland and the Czech Republic. There are already thousands of hectares of dead spruce. The risk of outbreak in Norway

spruce is more dangerous. Most bark beetles have predatory mites which keep populations in balance.

- Current large bark beetle outbreaks in temperate forests serve as carbon sources.
- In Ukrainian forests, the number, duration and severity of insect defoliator outbreaks have generally not changed over the last few decades with the exception of gypsy moth that has decreased and the European pine sawfly that has increased. The incidence of defoliators is highest in east Ukraine where pines have recently been planted in historically unforested land.
- Based on research on the spruce beetle in Slovakia, climate change is predicted to increase number of beetle generations and increase tree mortality across the range of Norway spruce.
- An example was given of pine processionary moth that expanded its range (altitude and latitude), as a result of increasing winter temperatures. Expansion has been documented in several studies in Italy and France.
- In subtropical Africa severe outbreaks of the fungus *Botryosphaeria* sp. on *Grevillea robusta* is increasing in severity and mortality with a drying climate. Many tree species are affected. Especially alarming is the attack on different *Eucalyptus* sp.
- Ash shoot dieback (*Chalara fraxinea*) is a new disease to Scandinavia from central Europe.
- The largest outbreak in history was recently recorded in Sweden of *Gremmeniella abientina* on *Pinus sylvestris* and *P. contorta*. Pre-outbreak weather is characterized by a cold and wet growing season followed by a mild and long winter period followed by another wet growing season. This fungus kills stressed trees.

Some of the future impacts on forests as identified in the session include the following.

- By 2050, 50 percent of forests may be affected by potentially phytotoxic ozone concentrations. Large increases in tropospheric ozone are projected, particularly in Asia.
- There will likely be an expansion of the range of the mountain pine beetle (*Dendroctonus ponderosae*) into Canada's boreal forest with climate change.
- Aspen and other ozone sensitive plants will continue to be affected by ozone deposition in North America.
- High insect mediated organic matter (insect frass/greenfall) inputs might enhance soil decomposition activity resulting in an elevated production of CO_2. Thus insect mass outbreaks might turn forests from carbon sinks to carbon sources.
- Highly coevolved relationships between insects and diseases and their hosts are expected to be disrupted. Host range expansion and contractions will cause crashes of some local populations of both hosts and their pests. Secondary pests may become more important in the future.
- Southern Europe diseases are predicted to move into boreal forests of Europe.
- Positive effects of climatic change include the expansion of tree species distribution and increased growth.
- Predicted mild winters and wet summers are likely to increase fungal disease outbreaks in Sweden.

While a number of examples were brought forth relating changes in climate and pest outbreaks, participants stressed that foresters need to be cautious about using climate change as an overall explanation for insect and disease outbreaks.

In discussing the future impacts of climate change on people and institutions, participants noted the following.

- Some climate change impacts may actually be positive such as lower snow accumulation that may reduce the winter survival of some forest pests.
- Economic assessment of mountain pine beetle infested stands in Canada find that replanting stands is not necessarily a good investment. Instead the study suggested that leaving the stand alone to develop after the beetle attack may be better. This is subject to change if wood demand or prices increase in the future.
- Society has assumed extreme expectations from forests and there may be a need to adjust our expectations of forest outputs as a result of climate change impacts, expected or unexpected.
- Extensive tree mortality from pest outbreaks has created awareness with the public and policy-makers to the importance of climate change.

Participants noted the following as potential management actions needed to adapt to climate change.

- There is a need to fill knowledge gaps related to natural enemies of forest pests under climate change scenarios. This includes research on the biology, ecology, and management of the complex suite of natural enemies (fungi, nematodes, mites and insects) and their relative abundance and nature of their association with forest pests.
- In declining spruce stands managers may have to plant other species.
- Studies show *Pinus contorta* is more resistant to *G. abietina* (European strain) than *P. sylvestris* in Europe. Plantations of *P. contorta* are currently restricted in Sweden but this policy may need to be reconsidered.
- The introduction of non-native species should be based on scientific knowledge, conducting pest risk assessments whenever possible because they can be very susceptible to pests if they are stressed in their new range.
- Biodiversified ecosystems are more resilient in a world of climate change. Better guidelines that are forward looking need to be developed. There is also a need for guidelines addressing large undiversified landscapes (such as pine in Canada) that are at risk and will continue to be so without management input.
- It was questioned how we can prepare to switch forests from one dominant tree species (Norway spruce) to another better suited species and how we can "buy time" through forest management to make the switch smoothly.

The following items were noted by participants through presentations and discussions in regards to policy needs.

- A global effort to conduct forest monitoring and research related to pollutant deposition needs to be designed to look at multiple pressures and interactions. These efforts are needed to assess risk to forests products and ecosystem services as well as opportunities to enhance forest products and ecosystem services. Air pollutant problems that started at the local level developed to have a global impact. Therefore well designed monitoring networks are required.
- Further legally binding protocols on air pollution abatement strategies are needed.
- North America and Europe need to harmonize forest monitoring and databases and efforts should be made to include the needs of developing countries.
- Methods to use lichens as air pollution severity indicators in forests need to be developed.
- More research and management on ameliorating forest pest damage is needed. There is a data gap especially with pest parasites and predators. The response by pest species that are regulated by natural enemies are not as easy to predict as those regulated by host-plant relationships.
- Focusing on single stress factors may lead to improper policy development.
- Governments tend to favour funding forest health modelling (short-term) rather than monitoring (long-term and expensive). There is a need for a balance of both options. Partnerships for monitoring need to cross political boundaries. Selection of appropriate indicators used in monitoring is difficult. Developing countries often have no capacity for forest monitoring. Multi-national or international monitoring efforts can be improved or developed.
- Invasive species networks need to be expanded and linked with one another. Existing databases and information need to be widely shared.
- Remote sensing techniques need to be improved to detect decline and dieback symptoms earlier.
- Vulnerability assessments should focus on monitoring high risk areas.

Session 6. Silviculture and production of wood and non-wood forest goods

Summary report

Presentations and discussions in this session identified the following examples of past and present changes in forests that could be attributed to climate change.

- Lichens comprise up to 80 percent of winter reindeer diet in boreal forests. Forest management affects lichen availability in many ways. Current conditions of young dense forests have reduced arboreal lichens; logging residues make ground lichens unavailable. Growing seasons have increased in northern Sweden in the last decade which is expected to affect lichen abundance.
- Scots pine in the Czech Republic has greatly increased in recent years. They are often stressed by growing on poor desiccated sandy soils. Moreover, climate trends continue to become drier and warmer.
- A potential source of clean energy is an increasing consideration under climate change conditions. In the US, many forests are densely stocked owing to fire suppression practices. Much of this low quality wood would be suitable for biofuel production if economically viable. Economics of forest biomass utilization is often related to proximity to a processing plant.
- Windstorms that uproot trees often provide microsites allowing natural forest regeneration in Eastern Europe. Spruce is more vulnerable to storm events than hardwoods and even-aged stands are more susceptible than uneven-aged stands.
- Norway spruce is an important species in German forests. Thinning following the extreme drought (hot/dry) events of 1976, 1992, and 2003 showed that the resistance against drought stress cannot be significantly improved by thinning. However, the resilience, as measured by the recovery of basal area growth, was more rapid in trees from heavily thinned stands.
- Foresters are being asked to quantify the impacts of harvesting and thinning on carbon dynamics (net carbon exchange with the atmosphere). In Canada, balsam fir ecosystems recover photosynthetic uptake relatively quickly after thinning by a variety of means and this response offsets additional ecosystem respiration due to decomposition of logging residues. It is estimated that a clear cut and unplanted site in the balsam fir ecosystem will become a net sink for carbon in year 6 after harvest.
- The focus of silviculture has been fast-growing trees. As a result the robustness of natural stands has been reduced with modern silvicultural practices. Foresters need to work with ecologists and geneticists to restore the vigour of diverse natural stands even when non-native tree species are included in the mix. There is a need to identify the tree traits that should be emphasized to provide forest ecosystem stability under the stresses of changing climate.

Some of the future impacts of climate change on forests and on people and institutions that were identified by participants include the following.

- Predicted longer snow-free seasons, increased ice crust, and increased tree productivity are expected to decrease accessibility to lichens by reindeer. Increased forest practices such as clear-cutting, fertilization, decreased rotation time, and road creation will also negatively affect lichen availability to reindeer. Conversely, the positive effects of warming and associated increased forest management may provide forage other than lichens to reindeer.

- Severe storm events are expected to increase in Europe causing more wind damage to forests, are even-aged stands especially at risk.
- Excess woody debris in US forests that is not suitable for other wood markets potentially offer a promising source of biofuels while effectively reducing the risk of stand replacing wildfires.
- Employing silvicultural actions on forests affected by climate change will influence non-wood forest products and ecosystem services.
- Some research found that large, fast-growing, dominant trees may be more susceptible to drought perhaps because they have large crown to root ratios.
- Creative silvicultural techniques will be needed to manage the transition of stands and landscapes where one or more species is beginning to die out and the establishment of a new suite of species.
- Managing native species that are well adapted to a site should become higher priority.
- Developing a market for wood biomass in local forest communities may provide an economic boost to local economies that are suffering from a depressed lumber economy.
- Non-wood forest products will be increasingly important in the future but little effort has been given to planning for their sustainability in climate change scenarios.
- Meetings such as this Forest Adaptation conference need to held in developing countries to allow a maximum number professionals from the region attend. Educating young professionals from developing countries (now) to deal with forest adaptation processes is important. IUFRO is sponsoring a Special Program for Developing Countries (SPDC) that can promote this interaction but additional sponsorship is needed for this program.
- The full economics of using wood biomass should be calculated to encompass all costs, for example the reduction of firefighting costs.

Participants discussed potential management actions and identified the following options. Sustainable development of reindeer husbandry can be improved with long-term joint planning between forestry and herders to sustain lichens. Scots pine monocultures in Czech Republic can be thinned to support climate change adaptation of young trees by reducing competition for water. Promoting uneven-aged stands with a mix of naturally regenerated hardwoods will provide more climate change resistant stands. Silvicultural treatments that include biomass utilization strategies may accomplish socially and economically acceptable restoration techniques for forests affected by stresses from climate change. As forest conditions evolve under climate change we will be continually redesigning silvicultural systems to address future questions. Maintaining the flexibility needed to applying adaptive management will be critical.

Existing silvicultural data, for example tree ring data or existing long term trials, can be used by scientists today to help answer climate change related questions without initiating new studies. In order to get answers soon we need to be "data mining" the rich resource of existing information. Here IUFRO's Global Forest Information Service (www.gfis.net) may be of help.

Participants noted that more research is needed on the relations of non-timber forest products and services in climate change scenarios. Funding opportunities also need to be made available. Institutions need to make data available for sharing. Again IUFRO's Global Forest Information

Service (www.gfis.net) could be of help. Existing provenance studies will be valuable to create new studies in climate change conditions. New trials are also critical as many questions have no historical basis. Enhanced cooperation among institutions will be increasingly important. Initiating trials that require moving tree species into new areas may require a new set of transport regulations to allow research on species shifts into new areas while assuring safe introduction that will gain public approval.

Session 7. Biodiversity, conservation and protective functions of forests

Summary report

The following examples of recent changes in forests ecosystems and the forest sector that could be attributed to climate change were identified by the session participants.

- Bolivia is considered one of the richest countries in forest biodiversity yet one of the poorest economically. Deforestation and related CO_2 emissions continue to increase as forests are being converted to agriculture. Forest fires related to deforestation doubled over the period 2001-2006. Air quality is severely affected by forest fires.
- Across Europe, mountain forests are recognized to have protective functions to human communities from hazards such as avalanches, flooding debris flow, landslides and rockfalls. Past and present forest management is affecting soil and water properties that threaten the protective properties of mountain forests. Changing climate is thought to be worsening the risk of avalanche in managed mountain forests.
- The European Forest Institute (EFI) has summarized existing knowledge (literature survey) about the observed and projected impacts of climate change on forests in Europe.
- Mountain regions are expected to be affected by climate change at a greater magnitude than other regions. This has already been observed for the second half of the 20th century where temperature increase in the European Alps was two times higher than the European average.
- Landslides are very frequent in Indonesia.
- In India, deforested lands often remain wastelands. Soil and water processes are affected in a broad geographical area.
- Upward movement in elevation of beech in Spain has been documented.

Future impacts of climate change on forests as revealed through presentations and discussions include the following.

- If deforestation continues to increase in the tropical forests of Bolivia emissions will continue to increase on a national level and biodiversity will continue to decrease.
- Mountain forests that offer avalanche protection to human communities are highly susceptible to climate change. Risk maps developed to map current and future distribution of protection forests in alpine areas of Europe find a high degree of avalanche risk in European Alps (Norway spruce forests).
- An EFI project (see above) predicts a decrease in availability of some non-forest products; a shift in species affecting local biodiversity; and increasing phenotypic and genetic variations (local adaptation) as species are stressed by climate change. Future trends in forest growth are variable regionally across Europe.
- Forest fuelwoods provide about 40 percent of the energy needs of India. Deforestation is currently causing soil erosion, landslides and water shortages. Deforestation and climate change is contributing to the rapid recession of the largest Himalayan glacier. With rising costs of fossil fuels, deforestation is accelerating.

- Climate change impacts on the mountain forest ecosystems and forest goods and services demanded by society are likely to be more intensive compared to forests elsewhere.
- A vulnerability assessment of Argentinean forests using a climate change model and national forest inventory maps finds that biodiversity conservation under predicted climate change is most critical in the northwest of the country, particularly the mountain cloud forests.
- There is a strong link between high carbon sink forests and high biodiversity.

Participants discussed the future impacts of climate change on people and institutions.

- Socio-economic adaptations are constrained by old paradigms and resistance to changing current forest management practices.
- Boreal forests may have increased growth with climate change and have less biodiversity loss as a result.
- A model shows that predicted climate change scenarios will affect the distribution of life forms, its leaf area density as well as run off patterns across Mesoamerica.
- In Indonesia, increased landslide severity and frequency is expected with increased rainfall. Landslides are expected to cause damage to infrastructures, cost billions, and cause human mortality. Disaster prevention and hazard mitigation options should be developed from within the community.

A variety of potential adaptation measures or management actions were identified by session participants.

- In India, the use of biofuels is replacing wood fuels. More than a million hectares have been planted as Jatropha plantations which are proving to be an excellent source of biofuel and may have future environmental benefits particularly as protecting water resources.
- In Indonesia, can vegetation plantings be used to ameliorate the damage expected by landslides? It appears that a mix of tree species with deep roots and ground cover species with intense and strong fine roots will provide the highest slope stability in the area. This suggests that tree species selection could be an adaptation that reduces the landslide risk potentially exacerbated by climate change. Trees that have a high Index of Root Anchoring (IRA) and high Index Root Binding (IRB) tend to increase stability. Societal acceptance from local communities of the tree species proposed needs to be gauged in advance.
- In Argentina, using sensibility and adaptive criteria to protect biodiversity in areas identified as most at risk in vulnerability assessment.
- Literature summaries are excellent tools but how do we (research and managers) capture the knowledge not available from scientific literature? Expert knowledge and novel approaches to develop knowledge are needed to inform adaptive measures and processes.
- Water policies and their economic effects need to be institutionalized.
- In Sweden, forests owners can insure their forests against loss; with increased risk of extreme climate events (storms, etc.), the monetary cost is expected to increase. Owners may be less willing to apply costly adaptations if insurance is not available to protect their investment from losses.

- Areas such as Mediterranean forests on steep slopes have little economic value therefore result in limited potential for adaptation measures.
- Economically viable forests will more likely result in the implementation of adaptation measures in changing climates.
- A hindrance to adaptation measures is the societal orientation towards close nature forestry where nature is defined by historical views that may not be accurate in changing climate. Society's expectations of forest services and products will need to adapt to changing conditions.

Participants noted the following needs and policies that would be most effective in supporting adaptation of forests and the forest sector to climate change.

- Proposed land use change policy in Bolivia could result in 97 percent CO_2 abatement by reducing deforestation.
- There is an urgent need to systematically study the adaptive ability of different regions.
- Methodologies and tools for vulnerability assessments are lacking. These tools are a prerequisite for designing adaptive measures.
- Water policies need to be improved at local and country levels.
- Sensitive, rare and endangered species are unarguably at high risk under extreme climate variation scenarios. Who pays the cost of conservation of species or habitats especially when they occur on privately owned land? Conservation targets and monitoring are at one scale but conservation implementation is enforced at another scale.
- Conservation reserve networks in Europe are very rigid – if a conservation area is defined it remains in place in perpetuity. A more flexible system may be needed under changing climate. Compensating a land owner in 20 year terms may be better in changing climates as to be able to move protection to a more biological rich area while putting a less rich area back into active forest management. Additionally, attention to protecting forest processes needs to be made at landscape levels and for long terms.
- Policies and measures developed for adaptations should involve local communities.
- Setting priorities for areas to apply adaptation measures is particularly crucial in countries with little resources.

Session 8. Socio-economic functions and livelihoods

Summary report

Participants identified a number of examples of recent changes in forests ecosystems and the forest sector that can be attributed to climate change.

- In arid and semi arid lands, increased deforestation, forest degradation and desertification in ecosystems that have low adaptive capacity have been caused by land-use change, livestock fodder, fuelwood foraging and illicit harvesting that have resulted in major sand storms, reduced irrigation water, dropping water table, reduced agricultural productivity, invasive species, migration and urbanization.
- Greater incidence of human-wildlife conflicts due to altered ecosystems, water access and feeding patterns.
- Land degradation, unpredictable rainfall, shrinking glaciers, water shortages, population growth.
- In Scandinavia there is a general acceptance of climate change as a reality that impacts forests and forest management.
- Increase in drying or falling levels of watercourses, lakes and rivers due to droughts.
- Changes in forest ecosystems are exacerbated when combined with increasing population growth and pressure.
- Impacts of climate change are not the only drivers of land-use and social change; these are interlinked with other environmental, social and economic factors that are difficult to isolate.
- Impacts of severe drought in forests and agricultural systems continue several years following the event.
- Changed demand for tourism and recreational services and patterns will cause changes in economic benefits, in some instances positive and negative in others.

It was noted that reduced agricultural productivity resulting from extreme weather events (e.g. drought) in the future may cause farmers to encroach on forests to maintain their livelihoods which in turn can cause deforestation and forest degradation. They also noted the following future impacts on people and institutions.

- There will be increased vulnerability of forest dependent communities in response to changes in quantity and quality of wood, fibre, fuelwood, food, fodder, medicines, and social and ecosystem services.
- Change in temperatures and rainfall will change forest ecosystems, forest health and vitality, forest cover, incidence of biodiversity, streamflow and snow cover patterns that will impact the provision of forestry goods (wood and non-wood forest products) and services, such as tourism, recreation and ecosystem services, that will impact communities.
- The negative economic impact of climate change can be severe in rural communities, particularly when the community forest governance is not functioning properly.

Forestry institutions need to change to include climate change and subsequent adaptation to the problem in their forests and forest management policies, strategies and practices.

Adaptation to climate change can vary based upon demographics (age), perceived risks and opportunities, level of uncertainty of adaptation options and spreading risks (e.g. mixed species). Some potential management actions recommended by session participants to maintain the socio-economic benefits of forests included:

- community plantings, school programmes, partnerships with the private sector, village woodlots, agroforestry systems, shelterbelts, awareness campaigns through the media and field demonstrations, children's education;
- opportunities, greening campaigns, nursery development, research to monetize environmental and socio-economic benefits of urban forestry and investment in environmental management;
- greater involvement in joint forest management for wood and non-wood forest products, deeper wells, migration to cities;
- use of irrigation systems to overcome water shortages in agriculture to maintain productivity.

In countries with high population pressures, land use issues and vulnerability to drought and extreme weather events, agroforestry can provide diversification in spreading risk to climate change, particularly with drought resistant species.

Through presentations and discussions, session participants noted that there is a need for:

- supportive policies to promote greater joint forest management, community forest management, afforestation, reforestation including agroforestry (smallholders), availability of microfinance, training in non-wood forest product management, marketing and manufacturing;
- greater role for women;
- support to community forest management with sound governance, strengthening institutions, greater participation and education, greater accountability, reinforced monitoring, and community access to benefits;
- promotion of agroforestry, afforestation and reforestation, Clean Development Mechanism (CDM) projects for developing countries;
- harmonized and consistent land-use policies, supported by strengthened institutions;
- climate change adaptation education, training and public awareness;
- recreational and tourism policies that will adapt to new recreational "norms", diversification of recreational activities, use of new technology and new individual behavioural changes;
- consideration of insurance cover options against the impacts of climate change;
- support for more research into drought tolerant species for agroforestry, afforestation and reforestation;
- clear and consistent migration policies.

Session 9. Innovative management and policy approaches to climate change adaptation

Summary report

Future climate change impact scenarios have been developed, but uncertainty about risks and responses remain. The impact of climate change and extreme weather events on forest ecosystems is generally framed, with anticipated increased impacts of higher temperatures, less rainfall in some areas and higher rainfall in others, increased risks, incidence, and severity of impacts of typhoons/cyclones, fire, insects, diseases and other pests risks.

Participants discussed potential adaptation measures and management actions and identified the following options.

- Focus priority initiatives on the communities and forest ecosystems that are the most vulnerable (hot spots) to climate change and support (achievable) response options with the necessary resources (personnel and funds).
- Increase public awareness of the impacts and need for adaptation management in response to climate change and extreme weather events, document success stories and support champions.
- Elevate the importance of the social sciences in the adaptation of communities, land-uses and forest management and engage in participatory planning, community and forestry dialogue, shared understanding and long term goals in adapting forest management to climate change.
- Greater focus in adaptation of forest management response options that address risk aversion through breeding programmes (species that are robust, flexible, adaptable), greater incorporation of mixtures (species and provenances), introduction of structural variation (uneven spacing, age classes and silviculture) and simulation of near to nature forests (semi-natural) and integration of productive and protective functions of forests across landscapes to maintain, as far as possible, the functions of forests in the provision of goods and services.
- Use simple tools (illustrations, landscape models, best practices guidelines, etc.) that communities and foresters can visualize and understand before they can have dialogues on responses towards closer to nature forests that are closer to people and communities. This requires collaborative, adaptive forest management approaches in the planning and learning by doing in the implementation, constantly reviewing based upon emerging conditions and forest management performance.
- Increase monitoring, early warning, detection, preparedness, prevention, early response/suppression and restoration in integrated, inter-sectoral, landscape approaches to fire management and forest health (insects, diseases, pests and invasive species).
- Improve knowledge in past and present climate change impacts, with the aim to quantify the drivers of change and to reduce the uncertainty, understand the sensitivities, vulnerabilities and the needs for adaptation.
- A proactive management response to climate change is to identify management goals, evaluate vulnerabilities, risks and uncertainties to climate change, derive a management response strategy (toolbox) that will increase resilience by minimizing current stressors and protect against direct and indirect impacts of climate change, i.e. creating resilience, respond to climate influences (e.g. adopt landscape approaches, connect fragmented forests, expand genetic and structural diversity,

establish refugia), constantly seek new opportunities, constantly reassess responses and adapt/realign goals under changing conditions.

- Confront what can and cannot be done – do the doable – adaptation to climate change is as much a cultural and intellectual challenge as it an ecological one – think outside the institutional and intellectual silos.
- Build partnerships and collaboration with the key land-user groups, including the private sector.
- In the face of incomplete scientific knowledge, data and information, a start must be made with what we currently know, constantly reassess, adapt to new goals and management responses, focus on win-win adaptation options. As most impacts are irreversible, if we wait for more complete knowledge/technology, we will be too late and the climate change impacts may be greater.
- Protected area managers need to integrate protected areas into larger landscapes, include restoration activities, engage local communities, value protected areas, reduce barriers, prioritize more resilient habitats and protect against fires, insects, diseases and other pest attacks. Decision makers need to recognize the value of protected areas, incorporate climate change and disaster risk management into strategies and include protected area management in REDD strategies. Scientists need to develop new monitoring (species, soil, water etc), decision-making tools, build scientific capacity in developing countries and bridge the knowledge/technology divide between science and policy makers and managers.
- Promote in-situ and ex-situ conservation of genetic resources.

Participants concluded that there is a need to:

- integrate climate change and disaster risk management strategies, policies and institutions that focus on pro-poor and specific ecosystem, landscape or community hot spots;
- introduce climate change adaptation and mitigation policies, planning and institutional frameworks in governance that will undertake more intersectoral, multidisciplinary and integrated approaches, improve advocacy, strengthen awareness and capacity on climate change, carbon management and reporting, particularly in developing countries and least developed countries;
- provide greater commitment and capacity building, particularly in developing countries to REDD readiness towards Copenhagen, COP 15, December, 2009.

Session 10 - Climate Change and Forest Sector Adaptive Capacity

Summary report

Participants discussed the current changes in the forest sector related to climate change. Presentations from the EFI and Canadian researchers provided the following conclusions in this regard.

- The European Forest Institute (EFI) has through questionnaires to different EU-countries investigated the awareness and understanding of climate change issues and the willingness and motivation to take action. Findings from the questionnaire show that priorities are affected by region (vegetation/geographical/political), economical situation, national regulations and legal framework. Measures are focussing on reducing risks while little attention is given to potential benefits from climate change. Most common strategies being applied on the ground are selection of forest material and adaptation of silvicultural practices (e.g. thinning regimes).
- A Canadian (Johnston *et al.*) investigation with informal interviews and discussions with forest managers concluded that: institutional barriers were more important than technical; local knowledge is needed since adaptations must be local; and embedded science models are needed where scientists and practitioners work out strategies together.

The forest sector is expected to be impacted by a number of factors associated with climate change including increased occurrence of drought, windthrow, heavy rains and floods, fire, and pest and disease outbreaks. It was noted that such occurrences will impact the economic viability of the forest sector. If the future viability of forest sector is at risk, impacts on people and institutions could include unemployment in rural areas dependent of forest-based industries such as northern Canada or northern Europe.

Session participants discussed the adaptive measures and potential management actions needed to address the impacts of climate change on the forest sector. In the presentations and discussions it was distinguished between adaptive capacity, adaptation measures and the implementation or promotion of these measures.

Adaptation capacity is considered an important element of the function assessing vulnerability. This does not only apply to climate change but also to other challenges in the forest sector. Improving capacity to adapt to climate change can be improved by making the forest sector more viable, in particular through research and development and innovation.

A basic for discussing adaptation is to determine the needs of society to the forest. Depending on the definition of society's need/demands to the forest, adaptation measures have to be chosen. In particular European countries seem to define their demands according to the criteria for sustainable forest management. Canadian participants saw the criteria for SFM just as a basis to discuss and determine future needs.

Adaptation can be divided into biological or ecosystem adaptation (not discussed in depth in this session) and socio-economic adaptation to climate change. Participants noted a number of possible measures to adapt to climate change:

- improvements in technology (e.g. for harvesting, genetically modified trees), financial resources, institutions, human and social capital;
- on a forest management level - thinning to adapt the stand structure toward uneven stands and choosing adequate tree species (spreading risk, increasing biodiversity);
- improvement of infrastructure to facilitate harvesting (in the northern hemisphere climate change leads to shorter harvesting periods).

Participants noted that special focus has to be set on adaptation in tropical countries. In particular they noted that the negative impacts of biofuel production on domestic food production and deforestation have to be addressed.

Session participants suggested the following activities and policies would be needed to support adaptation of forests and the forest sector to climate change.

- Promote the dissemination of existing knowledge on climate change impacts and adaptation.
- Education of the public to make them aware of possible impacts of climate change as well as opportunities to react and adapt (and the associated costs).
- Taxes on carbon (or incentives for renewable energy) can help to make the forest sector more viable and thus be more prepared to take measures to adapt to climate change

Session 11. Tropical forest management and climate change adaptation

Summary report

Some recent or current changes in forests ecosystems that can be attributed to climate change identified by session participants include the following.

- In tropical ecosystems, there is an observed increase in temperatures and more extreme La Nina and El Nino effects including greater incidence and velocity of typhoons, heavy rainfalls, flooding and landslides, while on the other extreme, droughts that have reduced agricultural productivity and production, catastrophic fires and the impacts of insects and diseases that in turn have impacts on food security, poverty and livelihoods in vulnerable groups.
- Vulnerable communities that face failed agriculture and livestock caused by climate change and extreme weather events turn to forage/harvest in tropical forests as coping strategies for water, wood, fuel, non-wood forest products, food, fodder, medicines, etc., and even encroachment, that in turn causes deforestation and forest degradation.
- Due to deforestation and forest degradation in tropical rainforests, wet and dry forests, the functions and provision of goods and services are eroded. Dry forest ecosystems are identified as being the most vulnerable in some countries.
- The impacts of, and vulnerabilities of, communities to climate change and extreme weather events is diverse and depends upon the unique political, social, cultural, environmental and economic landscape that prevails in each context.
- Indigenous communities may not understand the science of impacts, but through their traditional knowledge they know how climate change impacts their lives and livelihoods and how they need to adapt. Examples: Drought = less water flow, wells dry, more time to collect water, quality of water decreases, more diseases, productivity of crops declines, crops fail, financial resources reduced, greater incidence of fire. Extreme heat = sleep outdoors, greater incidence of malaria, less capability to work, crops fail.

The participants discussed the future impacts of climate change on forests and on people and institutions and concluded the following.

- Greater encroachment, foraging and harvesting of tropical forests in illicit, informal and uncontrolled manner as people strive to cope with impacts of climate change and extreme weather events on agricultural activities and livelihoods
- Modelling of the impacts of climate change on tropical forest ecosystems is complex and in many instances there is insufficient reliable data, so future impacts on forests and forest species are difficult to predict.
- Vulnerable communities in tropical ecosystems will suffer greater through impacts on livelihoods, food security and poverty, but have the least capacity and capability to cope.
- In tropical landscapes where climate change and extreme weather events increasingly occur, vulnerable groups will increasingly encroach and overexploit forest ecosystems for wood, fuelwood, food, fodder, and medicines as coping strategies.

Potential management actions brought forth by session participants to address the impacts of climate change include: identifying vulnerable ecosystems and species; increasing protection in these areas; rehabilitating degraded forests; improving low impact harvesting systems; mainstreaming climate change in non-wood forest products and biodiversity management policies, programmes and management plans to enhance adaptation; monitoring forest biodiversity changes; considering innovative financing mechanisms; and increasing afforestation/reforestation; and improving natural forest management.

Capacity building is needed to strengthen developing country REDD (reduce emissions from deforestation and forest degradation) readiness to establish baselines and monitor deforestation and forest degradation in tropical ecosystems through a combination of remote sensing and ground surveys to derive REDD strategies to report to the UNFCCC process.

Modellers need to engage more with other stakeholder groups in their modelling and to translate their knowledge and technology into language that is understood by key decision makers.

There is a need for new solutions to new problems. We know how to manage forests of the past, but we need to adapt forest management practices in light of climate change in each specific context, taking into account scientific, traditional and management knowledge.

In tropical countries there is a significant problem in that there is serious lack of scientific data and information on which to make climate change adaptation decisions.

Forest scientists and foresters must engage with other scientific and land-use management groups in the landscape as their communities of practice, perceptions, and adaptation solutions can be quite different.

Session participants also discussed the policy options to best support adaptation of forests and the forest sector to climate change. Generally there is a lack of climate change adaptation governance, policies and legal frameworks in tropical regions, whether for livelihoods, natural resources management, forest management or non-wood forest products management and marketing.

The policy research framework methodology is a useful national, landscape or local decision-making tool to interlink institutions and people (scientific, academic, policy-makers, managers, investors, communities and communities of practice) and identify the bridges between stakeholder groups to identify information needs, resources, roles, information sharing and networks that can stimulate participation on specific issues, such as adaptation to climate change.

Participants stressed that there is a need:

- to focus on people, poverty alleviation, food security and livelihoods issues in communities vulnerable to the impacts of climate change, to diversify their income opportunities as a coping strategy.;
- for inter-sectoral dialogue to formulate more consistent, clear and cohesive natural resources management and livelihoods policies with particular regard to water, agriculture, energy, forestry, disaster risk management sectors and climate change strategies and coping mechanisms;
- for adaptation measures within policy and planning frameworks at the local level since there is generally a lack of adaptive capacity in local communities;
- for a shift in the way that scientists interact and bridge the gap between their scientific results and the use of these by policy makers, managers, investors, communities and other stakeholder groups;

- for greater dialogue across the international, national, sub-national and local divides with regard to impacts and adaptation strategies;
- to meld both traditional knowledge on understanding the problems and the solutions in combination with science and other support systems as indigenous communities have been adapting to change, including in climate for millennia;
- for a combination of macro and micro level planning to understand the specific impacts on communities and their coping strategies particularly since each social, cultural, environmental and economic context is different.

Due to the diverse nature of impacts and vulnerabilities there is not one fix all solution, but to work with stakeholder groups in participatory approaches to explore coping strategies and more flexible, integrated policies and approaches across sectors that better connect tropical forest ecosystem goods and services to climate change.

Session 12. Genetic and physiological adaptation to a changing climate

Summary report

1. Past or present impacts of climate change on forests and the forest sector

After some 50 years of tree breading there is relatively minor impacts on resistance breading, but: still some results are locally very important; few species have the tree improvement mechanism; not directed on problems where silviculture management options are limited (e.g. PW chestnut).

In the climate change race some species will be winners, some losers. Examples are already happening are spruces in Mexico and the northern US. Finding resistance genotypes is not the main challenge and could be done by screening a subset of elite genotypes across classes of pests and diseases.

2. Future impacts of climate change on forests

Prolonged drought and temperature increases result in flowering asynchrony among clones and thus, to a lack of random gene exchange, dramatic reduction of the potentially effective population size and the genetic basis of the seed crop that could be produced.

Populations of trees would become maladapted to the sites due to changes in climate. Climate change will cause diseases to become more destructive than before, sometime leading to collapses of species. Natural hybridization among species may be an important factor for the species adaptation.

3. Future impact of climate change on people and institutions

First targets are to develop a high resolution climatic model, species population response functions to climate change and predict future climatic envelops for different ecosystems and species ranges. Short rotation forestry using elite genetic material can be used to provide bioenergy feedstock and to reforest areas where previous species have been displaced.

4. Adaptation and potential management actions

Seed and breading will need to change under changing conditions. Genetic conservation will be paramount to save many species since genetic conservation is so expensive and difficult. Analysis will have to be made to determine and conserve certain species.

Selection of species and breading for resilience against pests, diseases, extreme events and calamities will be required. Already existing genetic tests can be used for deciding on movement of genetic material to increase adaptation.

5. Policy actions

Since tree planting proceeds at a pace of 1 percent of landscape per year, choices for genetic employment mast explicitly consider climatic change. Further monitoring is needed to identify the effect of climate change on forest tree phenology and its impact on the seed production and its genetics. Genetic resources in the developing countries are at risk because of lack of understanding. Urgent policy actions are needed to raise awareness and provide capacity building in the countries.

Session 13. Forest dieback and mass mortality: Assessment and early warning

Summary report

Participants noted the following recent changes in forest ecosystems that could be attributed to climate change:

- dieback of aspen in boreal/steppe boundary zone of North America;
- outbreak of *Diprion pini* in central Finland;
- dieback of relicts of *Cedrus atlantica* in Algeria;
- dieback of *Abies koreana* on a southern Korean island.

Some of the expected future impacts on forests noted by the participants included the following.

- Aspen productivity will decline, together with future harvest levels; mortality is projected. The question of how to, and how urgently to, salvage the timber is not clear.
- Most causal or predictive models were still under construction and were not yet used for early warning. In many cases remote sensing (with Modis, Laser or other remote sensing tools) supplied input data for causal models for tree decline or to assess the impact of climate change on environmental services, such as water runoff, water purification and nitrogen load. Field data observation was used less extensively (only in aspen and Korea fir) but seemed to provide the best correlations. Some imaginative indicators used for early warning were indicator plants, crown structure, leaf dimensions, leaf deformation (curling in *A. koreana*), basal area, biomass or diameter growth.
- It was noted that in all cases, the studies focussed on events that had already materialized. Projecting the future impacts needs much more time.
- None of the models were ready to be used as a formal vulnerability assessment tool in forestry. The Center for International Forestry Research (CIFOR) is striving to build such a tool, given that the United Nations Framework Convention on Climate Change (UNFCCC) compendium does not contain a forestry tool for vulnerability assessment. At this time, focus is on exposure and sensitivity assessment. All other components of vulnerability assessment are missing.

The future impacts of climate change on forests were discussed. Participants noted that only the ongoing work by CIFOR considers these impacts in Asia and two African countries and results are not yet available. In general, decline of forests and forestry in certain areas will cause economic problems or even collapses. For instance, the mountain pine beetle will cause economic hangover in the forest sector when growing stock is gone.

The ability to reduce the impact of forest mortality on local communities and economies is needed. This too is part of adaptation, not just the forest. It may not be possible to mitigate the cost of adaptation in poorer countries.

While neither of the presentations considered possible adaptation measures, discussions touched on the trend towards purely reactive adaptation, such as salvage logging. One possible option for anticipatory adaptation is spreading of risk, e.g by using different species or genets. Forestry needs to learn to live with, use tools for, and adapt its management to uncertainty.

Participants expect that there will be changes in forest species composition as a result of climate change. Some species will die but other will take over. Good management should be able to predict and utilize the dying species to the best use for society. Forest management needs to adopt species compositions to make the forest landscape ecologically sound and well adapted to the changing climatic conditions. Secondly management should go beyond wood and look into the ecological services and amenities of forests.

The concept which prevails now is reaction adaptation, which is simple responding to the changes which happened in the past. Participants noted the need to act proactively. We should be able to forecast threats probabilistically, act in anticipation in agreement to our perception of risk, and, generally, introduce adaptive forest management in an operationally feasible form. Harvesting schedule should be revised periodically after calamities. Hedging our bets is a good strategy. Predicting what will happen and react effectively to prevent or mitigate negative consequences.

While a lot of knowledge has accumulated, science cannot yet project and predict, for instance, if Korean pine (case addressed by the Korean colleagues in the session) will be able to survive and adapt autonomously o the new conditions. The Intergovernmental Panel on Climate Change (IPCC) is not yet able to project such impacts on forests. This limits the readiness and willingness of policy makers to introduce new policies. Scientists may only predict forest cover change with probability; uncertainty will remain and risk management is needed.

More experiments and case studies are needed to create better, more reliable and more comprehensive models. Forest inventory should be complemented with newly important parameters. Reducing forestry staff, and reducing the intensity and frequency of assessments would be counterproductive under emerging climate change.

Session 14. Forest dieback and mass mortality: monitoring and mitigation of consequences

Summary report

1. Past or present impacts of climate change on forests

The world is getting warm rapidly and forest mortality is on the raise. Forest mortality in Russia has been increasing over the past 20 years, although there are large year-to-year variations. Overall annual mortality seems does not exceed 1 mha, which is less then 0.1 percent of the total forest area. Analysis in Russian North-West shows that up to 90 percent of forest dieback and mortality in the region can be attributed to the climate change. Dieback triggers forest fires, insect infestation and more severe damages from more frequent natural disasters. The problems of mortality are likely to increase in the future.

By comparison, in Canada's boreal forests, fire alone impacts 1 percent of the boreal forest on average, with peaks of nearly 4 percent in catastrophic years. Although these are mostly ground fires, they cause mass mortality of 3 to 5 year trees. Natural background mortality in forested stands is currently also increasing in forests of western US.

Current forest dieback mostly occurs in the areas where forests are already environmentally stressed. The stresses are often related to droughts and other abiotic factors such as the loss of spring snow-cover followed by soil freezing (Alaska Yellow Cedar), or increased salinity in coastal deltas in Bangladesh caused by the reduced flow of major rivers (dieback of mangroves).

2. Future impacts of climate change on forests

Forest mortality has upward trend worldwide but has strong regional aspects. Preventive and suppressive measures are based on regional approaches, which address areas of high, medium and low risk mortality. Forest dieback will likely increase in the future with the warmer and drier climate. Effects of increasing temperature on extreme climate events are non-linear, as well as response of trees to these events. There is a risk of large multiplicative effects of climate on forest dieback in the future.

3. Future impact of climate change on people and institutions

Over 10 million ha of forest land in Archangelsk region is represented by over mature forest especially fragile in the face of global warming. This may have negative implications for the regional economy in the near future. Long-term monitoring of tree mortality helps to analyze historic trends, assess future risks and develop management strategies. Climate mitigation measures in Russia are currently developed in two ways: prevention and mitigation of forest mortality and establishing carbon accumulating forests on forestless land.

4. Adaptation and potential management actions

Forest management options for limiting the scale of the forest dieback are decreasing with the increase of the scale of mortality. Thus preventive management actions should be taken based on risk analysis. Management actions, such as density regulation as a short-term measure, or species change as a longer term action, can increase forest resistance to the negative impacts of climate change.

Remote sensing through MODIS can provide timely warning of change in canopy properties, indicating forest health conditions and need for preventive management actions. This technology is widely used in developed countries, but is not widespread in the developing world because of lack of capacities and resources. Management actions would require proper information support and feedback from the practitioners in the field.

5. Policy actions

Dieback of forests due to climate change is not a local or regional problem, but a global issue, which should be addressed globally. It is necessary to establish a global monitoring system with long term forecasting of the forest change, especially in boreal coniferous stands. There are no yet clear answers on the reasons of the mass mortality in Russia, Canada, USA and many other parts of the world. Russia will rejoin ICP to establish monitoring plots and promote international actions to address forest dieback.

The best information on risks is currently available for boreal and temperate regions. Tropical and sub-tropical regions generally do not have the capacity to perform such an analysis. It would be appropriate to pursue the implementation of forest risk assessments in developing countries.

Session 15. Scenarios and modelling for forest management planning

Summary report

Through presentations and discussions, participants noted the following recent and future impacts of climate change on forests.

- Changes in climate conditions (temperature increase, wind patterns, precipitation/moisture regime (moister or dryer conditions may occur depending geographical region)) expose forests to more stress resulting in increases in pest outbreaks. In general this leads to changes in forest types, changed distribution of forest ecosystems or, as in the case of Western Canada, to a change in tree line in mountain areas and an expansion of grassland.
- In western Canada, changes in fire patterns and increased fire frequency has not increased the risk of mountain pine beetle outbreak much, but epidemics are expected to become more severe, since forests are weaker and there is a decrease in number of tree species in vegetation zones.
- Expansion of vegetation period due to temperature increase (Germany, Canada, UK).
- The habitat of species will shift, including the habitat of endangered species, which will have impacts on protected areas and their management. As a result the designation of protected areas should take this information into account. The distribution of pest species will also change allowing for the introduction and establishment of pest populations in areas that have previously been protected.
- There are also positive effects of climate change on forests such as increased forest growth as noted in Germany.

Participants noted that all predicted future impacts are uncertain and dependent on model (uncertainty of models, input variables used, climate baseline used). The quality of site classifications and forest inventory data that are used as input for models could, in general, be improved substantially.

The impact of climate change on people and institutions were discussed. Session participants pointed out the impacts on protected areas and their management (discussed above) and also noted that it is important to include people who rely on forests in the development of models (decision support tools) and adapt models to their needs.

Participants considered potential adaptation measures or management actions that could assist in addressing the impact of climate change on forests and suggested the following.

- Changing tree species composition, choosing adequate proveniences and changing silviculture regimes (e.g. thinning) and management (e.g. shorter rotation age) were noted. Austrian modelling outcomes showed that increased diversity and complexity reduced vulnerability of forests. The identification and production of vulnerability indices and maps were suggested to lead to development of strategies.
- Climate change has to be taken into consideration when designating protected areas. For example, in the case of interior British Columbia, Canada, areas least susceptible to fire should be designated as protected areas.

- Urgent model applications are needed to decide what species and genotypes should be used for reforestation and to predict whether, and where, production forests can be maintained in the future in order to focus efforts. It is very important to identify sources of uncertainty in predictive models and to acknowledge uncertainties, i.e. there are often a wide range of possible scenario outcomes. It is a challenge to learn to make decisions that are resilient to an array of outcomes. Using the Ministerial Conference on the Protection of Forests in Europe (MCPFE) or Montreal Process criteria and indicators to assess vulnerability of forest ecosystems was recommended.

The following policy considerations were noted by participants as the most effective in supporting adaptation of forests and the forest sector to climate change.

- To better understand climate change, and in particular as decision support tools, models of forest ecosystems and forest management are crucial for management decisions. Models can be based on site conditions (soil and current climate), current vegetation, and driven by climate scenarios (IPCC or national). As a result vulnerability of tree species can be predicted and different forest management options (tree species composition, thinning regimes, rotation age) assessed.
- When using decision support models, first the goals of the user (decision-makers/practitioners/society) have to be determined. Often the uncertainty of future goals is not considered, only the biophysical uncertainty of models, however this dimension of uncertainty is equally important (and mostly neglected). Research on decision making has to widen. Insecurity in time scale must also be accounted for.
- The process of decision making has to be understood in order to properly use the tools and explain and communicate the results. For example in British Columbia, Canada models on climate change adaptation or results have been ignored by forest industry. It was stated in the discussions that it is of utmost importance to also include aspects of sociology, political science, psychology and cognitive science in order to get a deeper understanding of the process of decision making.
- It is crucial to teach forest practitioners how to use outcomes of models or how to deal with probability distributions, since climate modellers will never be able to give one likely scenario. Thus forest models are inherent even more complex, basing on the probabilities of the climate models. Information needs to be presented in a way that is useful for policy-makers, which is not yet the case. Messages to policy makers have to be different than messages to researchers (e.g. when presenting results for scenarios). Results must be adapted to the time scale of the respective stakeholder (politicians, business, etc). Other scientists than foresters are needed to interact adequately with society
- Local communities need to become involved in developing strategies for climate change adaptation.
- Models need to be adapted to appropriate geographical scale (global, national, local) and geographical region. Most models are currently in countries with sophisticated forest management and research.

Session 16. The "Swedish Model" as a Tool for Global Carbon Mitigation
Summary report

Active investments in forestry have led to almost a doubling of the carbon stock (in trees and soil) in Swedish forests over the past 100 years. Over the same time period, the sustainable wood harvest level has also doubled, resulting in high and sustainable production of wood and renewable energy.

The drivers that together have led to these developments have been:
- economic development leading to reduction of marginal agriculture and consequent return of forests over large land areas;
- long-term subsidies and regulations to stimulate raw material supply to the forest industry.

Similar drivers are now present in many developing countries. Forests are returning to marginal agricultural land following economic growth (at the same time as conversions of forest to commercial agriculture continues in some regions). Planted forests are expanding to meet increasing demands.

There is a biophysical potential to store very large quantities of carbon in forest landscapes that could significantly mitigate human-induced climate change at the global level. Following the Swedish experiences, this may be combined with an increased production and use of wood and fibre.

There is a market demand for mitigating climate change through forestry. Financial mechanisms are currently negotiated under the climate change convention, although the focus of the debate is often on reducing deforestation (i.e. reducing the conversion to commercial agriculture).

As an alternative, the opportunities to stimulate, through market mechanisms, increased carbon stocks in forests and landscapes on all land should be better investigated to inform the convention process that aim at a post-Kyoto mechanism in the Conference of the Parties in Copenhagen in December 2009.

Session 17. Opportunities for combining adaptation and mitigation

Summary report

1. Past or present impacts of climate change on forests and the forest sector

- Reported periodic calamities of spruce budworm in intensively managed forests of Canada are projected to spread further north with global warming, making adaptation of ecosystems of balsam fir and spruce a necessity. The mountain pine beetle outbreak in Canada necessitates reactive adaptation in the form of salvage.
- The 2005 storms and floods inundated the coast of Guyana, causing damages representing 60 percent of GDP.

2. Future impacts of climate change on forests

Calamities will affect harvest levels, economic returns and carbon storage. Hydrology of the affected areas will change, e.g. rising soil water tables due to elimination of forest as biological pump.

3. Future impact of climate change on people and institutions

Acute calamities and bleak prospects in Guyana have motivated the serious offer to sell all of the countries forests under REDD (reduce emissions from deforestation and forest degradation) to obtain finances for the country's development. Effects of afforestation and reforestation in developing countries include effects on water yields, fuelwood supply and availability of grazing lands. Similarly, planned afforestation of wastelands in India will affect not only carbon storage, but the supply of services from this land to people. Even wastelands are utilized by someone.

4. Adaptation and potential management actions

Mitigation will only function in the long-term if forests are adapted. Therefore, even Clean Development Mechanism (CDM) projects need carefully planned anticipatory adaptation, such as species choice and thinning regime. In contrast to the mountain pine beetle, spruce budworm impacts can be modified by foliage spraying, salvage logging. An optimal regime to adapt harvest levels and carbon storage was developed by a linear programming approach that maximized economic returns and on- and off-site carbon storage. Even reactive adaptation needs to be planned in the form of contingency planning, so that the after effects of a calamity can be dealt with swiftly. Proceeds from salvage logging can be used for future adaptation. In A/R projects, adaptation must account for the needs of the local population, e.g. water, firewood, and grazing land.

5. Policy actions

Monitoring of carbon storage faces practical restriction in all pools besides standing biomass; other pools are usually just modeled or calculated with default values. Mitigation and adaptation needs to include neighboring sectors, such as agriculture, which may otherwise cause leakage.

Monitoring is also necessary under REDD - carbon stock estimates in the Guyana forest varied wildly. In developing countries, adaptation or mitigation in the forest sector may affect the entire country and its development. Reactive adaptation, e.g. salvage of timber for fuelwood use, links mitigation of emissions with reactive adaptation.

A/R projects for mitigation could help people with environmental and social services. However, stringent rules curb A/R projects.

Session 18. Wood as a green building material

Summary report

1- Past or present impacts of climate change on forests

Concrete and steel are major contributors to GHG emission. In Sweden life cycle analysis (LCA) of wood processing (from seed to mill) shows that the major energy consumption is in transportation (50 percent), logging and hauling (30-40 percent). Meantime public perception is fairly positive towards use of wood in construction and facilitated adoption of the environmental legislation in some countries. For instance policies on green building are in place in New Zealand and are underway in few other countries.

2- Future impacts of climate change on forests

Wood should be used to substitute concrete and steel in construction to reduce GHG emissions. The ecological footprint (CO_2 emission) in construction of wood houses can be further significantly reduced by using low emission energy technology, efficient production (drying and sawing) and short distance transportation. After being used as construction material, wood can be re-used to generate energy, substitute fossil fuels, and reduce future forest harvesting.

3- Future impacts of climate change on people and institutions

Utilization of wood for construction reduces energy use for construction, but does not significantly reduce energy to operate the buildings. Efficient energy supply system such as bio-based CHP plants, may reverse CO_2 emission of both production and space heating during the building lifetime. This would require wood processing wastes to be used to replace fossil fuels for the building heating.

4- Adaptation

Wood preservation can prolong lifespan of the wooden constructions. Most treatments are toxic, but there are also environmentally friendly hydrophobic treatments, e.g. oil. No negative effects on wood properties have been observed. Harvesting residues and recovered wood should be utilized in construction and heating to address forest conservation and adaptation targets.

5- Policies

The clear message to use wood as green and environmentally friendly building material has to be communicated much better, in particular to respond to negative campaigns by the cement lobby. Green building certification is an essential competitive tool for the wood construction promotion. Polices should support energy efficient wood based construction and utilization of recovered wood and wastes for energy generation.

Land-filling should be avoided in general, due to the emission of CO_2 and methane from landfills. Rather use of wood waste for energy is to be encouraged. Legislations already exist in Sweden. European legislation would be desirable. Carbon emission standards should be included in the building codes. A post-Kyoto protocol should address this issue. Collaboration in the forest sector is needed to promote wood as environmentally friendly building material.