Expected Climate Change and Options for European Silviculture

Country Report Switzerland

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1.1 Forests

In 2005 approximately 31% of Switzerland or 12.746 km^2 were covered by forests (National Forest Inventory NFI, www.lfi.ch, accessed 25 July 2009). Forest cover varied between regions, with a minimum in the region central lowlands (25%) and a maximum in the Southern Alps (51%). The forest area increased by 5% during the decade from 1993/95 to 2003/05, however with considerable regional differences. The growing stock of 360 m^3/ha is among the highest values in Europe. Annual increment (9.5 m^3/ha) was slightly higher than the annual harvest and mortality (8.6 m^3/ha). The growing stock of broadleaved species increased by 10% all over Switzerland whereas the share of coniferous species slightly decreased (from 71% to 69%) during this decade. Norway spruce (*Picea abies*) is still the dominant tree species with a 45% share (Prealps 54% and Alps 70%). The second most frequent tree species is European beech (*Fagus sylvatica*, 18%) followed by silver fir (*Abies alba*, 15%). The total annual increment in the decade between 1995 and 2006 of 9.5 million m^3 has decreased by 3% compared to the previous decade and varied between 2.9 million m^3 in the lowlands and 0.7 million m^3 in the Southern Alps.

1.2 Forest functions

Timber production and protection against natural hazards are the most important forest functions. They have priority on 38% and 36% of the forest area, respectively. Other functions such as nature conservation are widespread, but have usually not highest priority (NFI data, in preparation).

1.3 Forest owners

Seventy-one percent of the forest area (8.887 km^2) are public forests and 29% are privately owned (3.591 km^2). There are big regional differences in ownership patterns. Private ownership is about 50% in the lowlands and in the Prealps, and about one fifth in the other forest regions. Public owners include civic[1] communities (42%), political communities (40%), and state forests (6%).

1.4 Political context

Switzerland is a federal direct democracy and the traditional role of Swiss federalism matters substantially for how the administration addresses climate change issues. The Swiss confederation, its 26 cantons (states) and the 2.636 communities of Switzerland, the latter being the backbone of direct democracy, are sharing responsibilities and competences in combating the negative effects of climate change at all societal levels. All policy measures related to forests are primarily the concern of the cantons, yet, protection forests, the preservation of biodiversity and tending young stands are subsidised by the federal government.

[1] Civic communities are sub-units of political communities originating from medieval times and comprise those residents holding the civic rights as members of this community whereas other residents are granted the rights of residence in the political community.

The federal law on reducing CO_2, which was promulgated in 1999 as a major landmark, envisages the goal of reducing CO_2 emissions by 10% in 2010 in comparison to 1990. To achieve this goal, several policy sectors are involved such as energy policy, environmental, traffic and infrastructure, forest and agricultural policy. Almost all political spheres which are related to adaptation and mitigation of climate change are thus organised to reflect and consider their own sectors' rationales and policies with their distinct administrative rules and traditions. Protection against natural hazards falls under the jurisdiction of the cantons which are assisted by the federation in the fields of prevention and early warning systems (e.g. flooding, heat waves). Generally speaking, there is an incompatibility between highly complex and dynamic natural phenomena such as climate change, and highly complex social systems such as public administrations which are implementing policies. The latter are usually oriented towards a homeostatic management of rules and regulations and do not easily transcend the limitations between departments.

These sector-oriented approaches would have to be coordinated from an overarching perspective as climate change is an encompassing phenomenon that is almost impossibly tackled from a sector perspective only. What would rather be required are cross-sector, target-oriented approaches to encompass impacts of climate change phenomena. The coordination, however, implies reasonable transaction costs, asks for new policy instruments (taxes etc.) and sometimes for new political institutions (e.g. foundations). Incentive taxes, for instance, to make houses more energy efficient, fall under the jurisdiction of the cantons, whereas mineral oil taxes are levied by the federal government. Other programmes such as wood energy heating systems, thermal pumps, and the construction of 'minergie' (low energy consumption) buildings are co-financed by the federal government. There are several federal incentive taxes, such as a fossile fuel tax and a heavy load road transport tax. Furthermore, private foundations such as 'myclimate' and 'Klimarappen' are active in the field of financially compensating CO_2 intensive activities and draw cash from consumers either directly or indirectly in cooperation with the state through levying energy taxes.

The transformation of international environmental law or non-legally binding international regulations into national and canton legislation is a time consuming process as the political and economic interests in the cantons of Switzerland are diverse and often contradictory and lobbying as well as counselling procedures in the wake of the parliamentary preparation of a law may take several years.

Another important policy is the 'Neugestaltung des Finanzausgleichs und der Aufgabenteilung zwischen Bund und Kantonen (NFA, i.e. Reform of Sharing Financial Commitments and other Tasks among the Federal Government and the Cantons)'. This process should clarify responsibilities, simplify financial transfers and increase equity between the federation and the cantons with regard to financial benefits and burdens. Environmentally relevant emissions are thus to be compensated by those economic units which benefit more from the production process causing them. The ecological transformation of Switzerland is a target that will have to be achieved in line with the international political commitments which have already been made or will be made by the Swiss Confederation. The implementation process, however, will have to be taken care of mostly by the cantons and at the local level by the communities. This rather complex line of transmission will certainly have its repercussions on the political system of Switzerland. As it is generally based on the achievement of political concord at all political levels, international climate politics will increasingly put their hallmarks on the process of finding political solutions to which all concerned stakeholders in Switzerland are willing to agree. This situation will be even more challenging if the global financial markets will not be so prosperous and be able to care for adequate growth rates and a good economic performance as it used to be before the outbreak of the crisis in September 2008.

1.5 Swiss climate policy

Switzerland meets the challenges of global climate change with a pro-active policy to reduce green house gases at domestic and international levels. Since the end of the 1980s the Swiss Confederation tried to stabilise the emissions from fossil fuel combustion. By signing the UN Climate Convention in 1993 and the Kyoto Protocol in 2003, Switzerland committed itself to cooperate in internationally coordinated climate protection policies. Switzerland follows two strategies: to reduce emissions of gases that are harmful to climate and to adjust this reduction to the ongoing developments. According to the Kyoto Protocol developed industrial countries such as Switzerland reduce their GHG emissions between 2008 and 2012 by 8% against the level of 1990. Besides CO_2 three more GHG (or group of GHG) are covered by this target. The present contributions to GHG emissions in Switzerland are as follows: CO_2: 85%, CH4: 7%, N_2O: 6%, CFCs and HFCs: 2%.

The reduction targets are to be achieved by several measures:

- Voluntary measures of private households and the economy
- A CO_2 tax was introduced on oil and gas for heating but not for fuel on January 1st 2008. This money flows back to individual households and the economy. From 2010 one third of the CO_2 tax revenue will be used for an energy efficient renovation of buildings
- Climate effective measures of other policy sectors such as the Action Programme Switzerland, Energy Law, weight based road tax for heavy transport vehicles (LSVA)
- Emission trade and other so-called flexible mechanisms of the Kyoto-Protocol

For the period 2012 onwards Switzerland will follow similar targets as the EU in order to achieve the CO_2 reduction goals that will be agreed upon in the Copenhagen Climate Conference in December 2009. In particular the development of energy saving and environmental friendly technology will be subsidised by the Swiss Confederation.

2 Impacts

2.1 Observed impacts

2.1.1 Observed climatic change

In Switzerland, 12 meteorological time series have been homogenised for temperature and precipitation ranging back to 1864 (Begert et al. 2005). The recorded temperatures at these stations indicate a temperature increase of 1.4°C in the 20th century, which is more than twice the global average (Rebetez & Reinhard 2008). Most of this increase occurred during the last 30 years, which showed a temperature increase of almost 0.6°C per decade (Rebetez & Reinhard 2008). While in the first part of the century the increase was mainly during winter (Rebetez 2001), the increase in temperature over the last 30 years occurred mainly in spring and summer (Rebetez & Reinhard 2008). Annual precipitation has slightly, but not significantly, increased (by 7-10%, Begert et al. 2005). The increase in precipitation occurred mainly during the winter months. An increase in extreme precipitation events has also been documented (Schmidli & Frei 2005).

2.1.2 Observed impacts on ecosystem dynamics and functioning

Phenology of vegetation

Spring plant phenology in Switzerland has also advanced over the last 20 years in accordance with the observed spring warming (Defila & Clot 2001, Defila 2001). In autumn, phenological phases show a slight tendency for delayed occurrence. These findings are in line with studies using the whole European phenological network (Menzel et al. 2006). Long-term needle elongation measurements of European larch (*Larix decidua*) at high altitude show a 8-11 day advancement of the date when 50% of the final needle length is reached for the period 1988-2006 in comparison to the period 1972-1987, corresponding to an increase in mean April and May temperatures of 1.6°C between the two periods (Dobbertin & Giuggila 2006). Fig. 1 shows the percent of final needle length reached by early June for the site Sils-Maria and the development of mean temperature in April and May at the same location. This advancement after the year 1988 was also found by Studer et al. (2005) who found an overall advancement of 15 spring phenology phases between 1965-2002 of 1.5 days per decade (range 1.0-2.8).

In 2007, with the warmest spring ever measured in Switzerland, needle growth was even 23 days advanced compared to the period 1972-1987 (Dobbertin et al. 2007, Dupouey et al. 2008). For the whole of Switzerland the phenological year 2007 showed new records in one fourth of the dates of all phenological observations (Defila 2008, Rutishauser et al. 2008). This was unique for the Swiss phenological network which started in 1951. According to historical records only two other occasions may have had similar or earlier phenological advancements (Rutishauser et al. 2008).

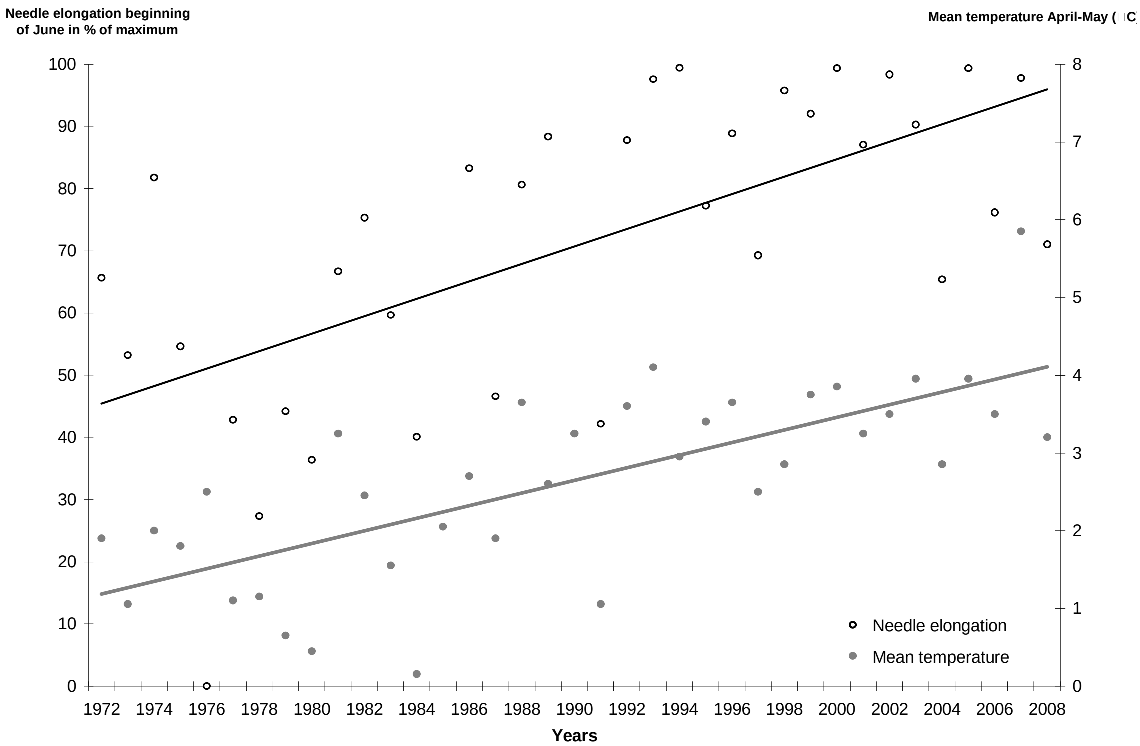

Fig. 1. Trend in mean temperature for April and May since 1972 and the percent of needle length of European larch (*Larix decidua*) reached by early June at Sils-Maria, Engadin Valley, Switzerland (1820 m a.s.l., observed data points with regression line, Dobbertin unpublished).

Change in distribution areas of plants

In Switzerland the east-west orientation of the Alps makes northward migration of plants and animals difficult. In contrast, the upward shift in altitude of plants and animals is a good indicator of the observed climate change. Walther et al. (2005) found an increased species diversity of high alpine summit vegetation in Switzerland with an accelerated trend since 1985, in accordance with the observed warming trend. Tree species, on the other hand, cannot easily shift in altitude, in particular when their seeds are heavy and not dispersed by animals, when microclimate or local site conditions prevent a successful establishment, or when land management is preventing the upward movement. While a slight upward shift of the tree line is observed in Switzerland, it is much smaller than would be expected based on the temperature data (Zimmermann et al. 2006, Gehrig-Fasel et al. 2007). The main reasons for this lagged response are grazing at high altitudes and still prevailing extreme climatic conditions during seedling establishment.

Comparing surveys in 1910 and 2002/03 in Swiss Valais, it was found that pine mistletoe (*Viscum album* ssp. *austriacum*), a hemi-parasite on pine species, has advanced by 200 m in altitude over the past century (Dobbertin et al. 2005a). The observed increase in species range was in line with the observed increase in winter and spring temperature, the time when seeds are dispersed by birds and germination takes place. Pine mistletoes have been shown to have high demands for transpiration and can therefore increase the water loss of pines under conditions of drought. They are therefore contributing to the observed pine decline at low altitudes (Dobbertin et al. 2005a, Dobbertin & Rigling 2006).

In parts of Switzerland, mainly the warm regions south of the Alps, more and more thermophile species are becoming invasive in the forest area (Walther 2001). These include evergreen broad-leaved tree species (Walther et al. 2001) and introduced palms (Walther et al. 2007). Although these non-native species have also increasingly been planted in gardens and parks, a relationship with the observed reduced number in winter frost days could be shown (Walther et al. 2007).

Insect pathology and distribution area

Increasing temperatures are expected to affect the population dynamics of insects and pathogens in forests via increased development and reproduction rates (Wermelinger & Seifert 1998, 1999). In Switzerland and other parts of central Europe the spruce bark beetle (*Ips typographus*) has caused extensive damage to Norway spruce following the two storms Vivian (February 1990) and Lothar (December 1999, see Fig. 2, Forster et al. 2007). While damage to standing trees reaches its optimum 2 to 3 years following the storms, it is interesting to note that warm weather such as in 2000 has accelerated this development and the extreme heat and drought in 2003 have lead to an explosion of the otherwise already declining population reaching an all-time maximum in this year.

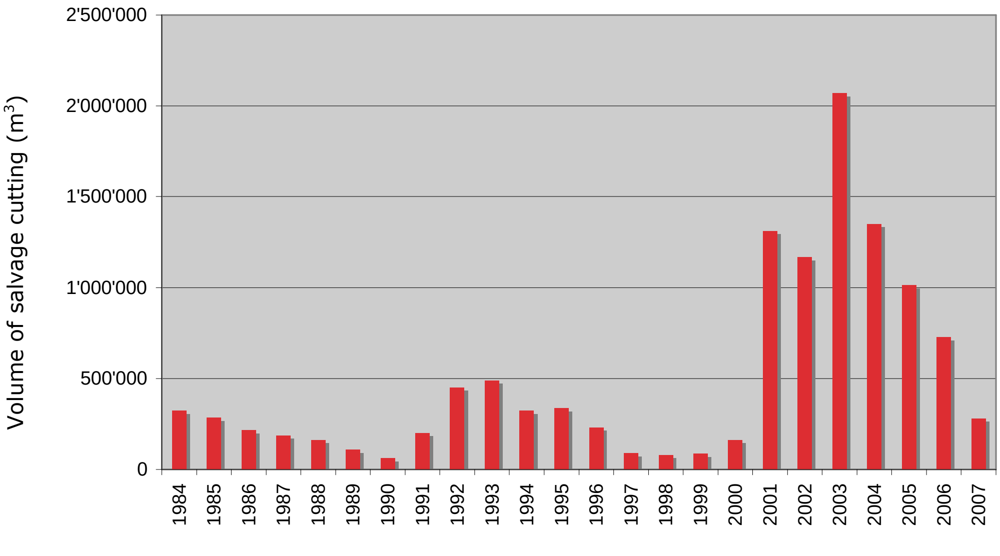

Fig. 2. Development of spruce bark beetle related salvage cutting in Switzerland since 1984 (Forster et al. 2007).

The temporal development of bark beetle related mortality of Scots pine (*Pinus silvestris*) in the Canton of Valais is usually associated with drought episodes, but not storm damage. Periods of high mortality since 1900 were not only associated with drought periods (such as in the 1940s, 1971-1976 and 1990-1998), but also with periods of above average spring and summer temperatures (Fig. 3, Dobbertin et al. 2007).

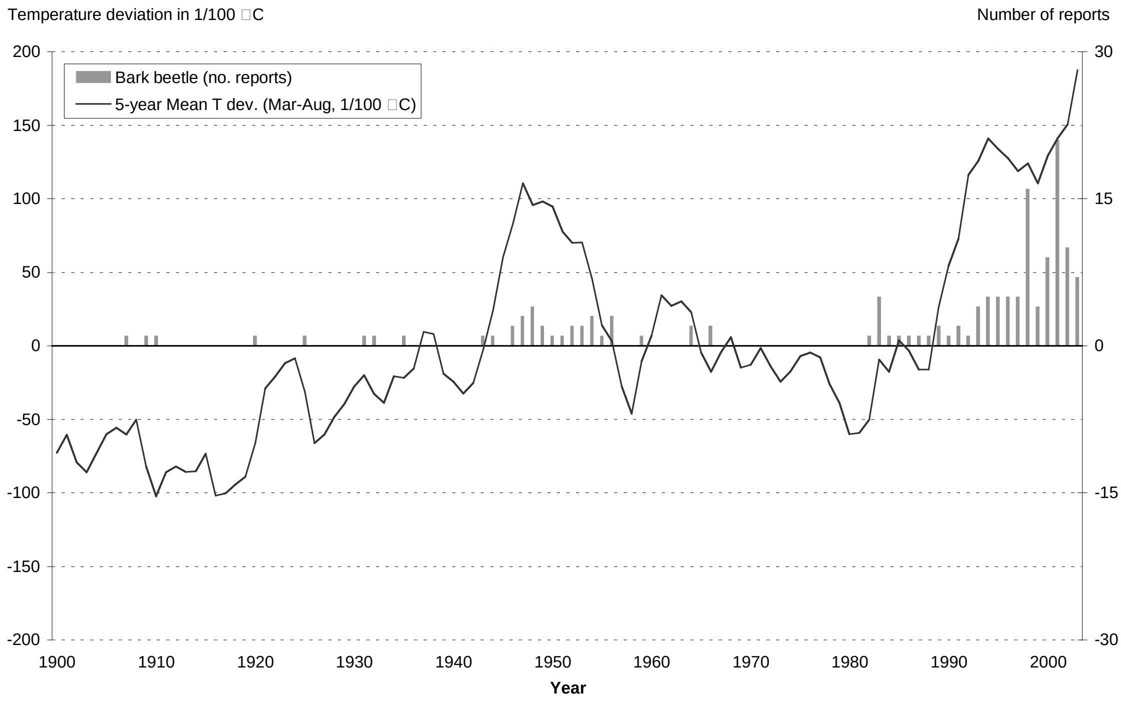

Fig. 3. Recorded bark beetle related Scots pine mortality and above long-term average (1961-1990) spring and summer temperatures in the Canton of Valais (Dobbertin et al. 2007).

Change in productivity

Several studies in Switzerland have recorded increased tree growth in recent decades (Bräker 1996, Köhl 1996, Zingg 1996). Increased growth had been mainly observed in the northern lowlands, but recent studies of uneven-aged plenter forests show increasing tree growth at mid altitude (Zingg & Bürgi 2008). The causes of this increased forest growth are not known, but have been generally attributed to a combination of change in forest management (including decrease in nutrient removal from forests), nitrogen deposition and temperature increase. The European-wide study RECOGNITION found increased tree height growth of Scots pine, Norway spruce and European beech of 25% over the last four decades (Kahle et al. 2008). Most of this change was however attributed to nitrogen deposition and only a smaller portion to an increase in temperature. The only Swiss site included in the study (European beech) also showed unexpectedly fast height growth in recent decades indicating an increase in site productivity of both young and old stands (Dobbertin 2005).

In a recent European study that included several of the Swiss long-term forest research sites (LWF), nitrogen deposition correlated well with higher current growth of Scots pine, Norway spruce and oak species, on sites with different site productivity, stand age and stand density (Solberg et al. 2009, Laubhann et al. 2009). An additional nitrogen deposition of one kg corresponded to an increase in growth of roughly 20 kg in carbon (de Vries et al. 2008). For European beech and Norway spruce above average temperatures during the studied period were also positively related to tree growth (Solberg et al. 2009). The effect of drought on growth was only negatively significant for Scots pine (Solberg et al. 2009), but the information on precipitation was less reliable than that for the other variables.

Provenance trials in Switzerland have shown that tree height and volume growth decreases in general with increasing altitude for the same provenances and tree species (Burger 1941, Dobbertin & Giuggiola 2006). While air temperature is expected to be the most important explaining variable, other factors such as soil type, soil mineralisation rate or wind and snow may also contribute to the decline in growth with altitude. These provenance trials had all been conducted in regions with sufficient precipitation. In some dry inner-alpine valleys, such as the Rhone valley, tree height actually increases with increasing altitude related to increasing precipitation and decreasing temperature with altitude (Dobbertin & Giuggiola 2006).

Observed disturbances and extreme events

The climatic extreme events that cause the most disturbance in forests in Switzerland are winter storms (Wohlgemuth et al. 2008). The most severe winter storms occurred in 1990 and 1999 (Dobbertin 2002, Mayer et al. 2005) causing damage to 4.9 and 14 Mio. m^3 of timber, respectively. Over the last 50 years the damage to Swiss forests due to winter storms has almost exponentially increased (Usbeck et al. in press). Usbeck et al. found that the total reported storm damage to forests of the past 50 years was more than 20 times higher than that of the two preceding 50 year periods (Fig. 4). Even when the volumes of storm damaged trees were adjusted for the increase in growing stock and forest area, they still increased by a factor of nine. Usbeck et al. (2009) could relate the increasing forest damage in the Canton of Zurich to the measured increase in extreme wind gust frequency. Other climatic factors that most likely contributed to the increase in storm damage were higher winter precipitation and less severe winter frost reducing the resistance of trees against uprooting during winter storms (Usbeck et al. in press).

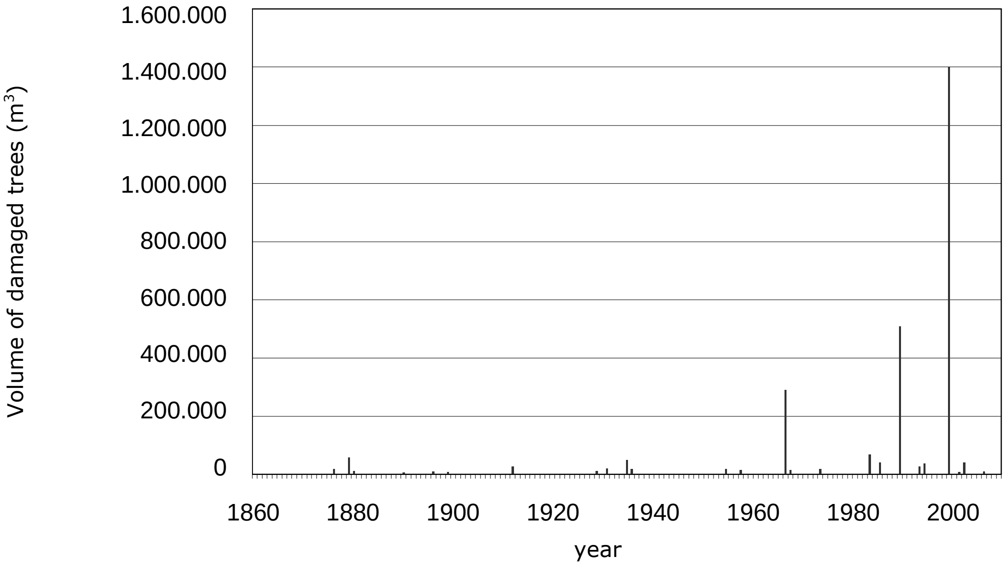

Fig. 4. Storm damage to forests in Switzerland due to winter storms for the period 1860-2007 (Usbeck et al. in press).

Forest fires in Switzerland are most frequent south of the Alps (Conedera et al. 2006, Reinhard et al. 2005), but occur also in the central Alps (Gimmi et al. 2004). In contrast to most regions in Europe, forest fires are here most frequent in winter and spring when drought periods frequently occur and large amounts of accumulated litter are easily ignited. So far no clear increase in forest fires has been observed or could be clearly linked to climate warming (Wohlgemuth et al. 2008) although climatic conditions are increasingly favourable to fires (Reinhard et al. 2005). This paradox can be attributed to changing human behaviour (Reinhard et al. 2005).

Other important extreme events are droughts. While in the dry inner-Alpine valleys such as the Valais drought is a frequent phenomenon (Bigler et al. 2006, Rigling et al. 2006, Dobbertin & Rigling 2006), north of the Alps severe drought is less frequent and usually only causes temporary tree growth reductions (Zingg & Bürgi 2008). In the Rhone valley of the Canton of Valais, Scots pine has been declining with highest tree mortality at low altitudes in the driest areas of the central Valais (Dobbertin et al. 2005a). In contrast, broadleaved tree species such as downy oak (*Quercus pubescens*) progressed in recent years (Rigling et al. 2006). Mortality increased following hot and dry summers (Dobbertin & Rigling 2006) and was higher during periods with above-average spring and summer temperatures (Dobbertin et al. 2007). Ring width comparisons of living and dead pines allowed developing mortality prediction models that revealed the strong effect of drought on pine mortality in Valais (Bigler et al. 2006). Studies of possible species-specific physiological mechanisms for such vegetation dynamics are still very rare (Zweifel et al. 2007, Zweifel et al. in press). Such mechanisms would be of interest because they could provide causal links between climate change and the performance of tree species.

The exceptionally dry and hot summer 2003 caused strong reduction in tree growth at lower altitudes in Switzerland (Jolly et al. 2005). Tree growth on long-term research sites at altitudes below 1200 m declined, while tree growth at high altitude sites even slightly increased (Jolly et al. 2005). This effect was highly correlated with water availability at the lower sites and increased temperature during the vegetation period at high sites (Pannatier et al. 2007). While for the whole of Switzerland only a slight increase in tree mortality was reported (with the exception of spruce bark beetle related mortality) following the summer of 2003, in the dry Rhone valley 30% of the Scots pines have died locally (Dobbertin & Rigling 2006). This may have been due to the extremely low precipitation in the region (April-September 2003 only 50% of the long-term average) coupled with the extremely high maximum temperatures measured here (Renaud & Rebetez 2009). However, in a study using many growth and yield plots in Switzerland with stand growth data covering several decades, growth reductions in the summer 2003 are neither large nor exceptional (Zingg & Bürgi 2008).

2.2 Expected impacts

2.2.1 Expected climate change

Climate change scenarios for Switzerland predict an increase in summer temperatures of around 3 °C by the year 2050 and a decrease in summer precipitation (Frei et al. 2006). Such a climate shift will dramatically change the competitiveness of tree species in an Alpine environment and their resistance to diseases and insects. For future precipitation, an increase in extreme events is also predicted (Frei et al. 2006), while more hot spells are expected in summer due to increasing variability in temperature (Schär et al. 2004). The increases in summer drought spells are expected to result in an increased frequency of drought periods affecting both agriculture and forestry (Fuhrer et al. 2006).

2.2.2 Expected impacts on ecosystem dynamics and functioning

According to Theurillat & Guisan (2001) the European Alps appear to have a natural inertia and thus to tolerate an increase of 1–2 °C of mean air temperature as far as plant species and ecosystems are concerned in general. However, the impact of land use is very likely to negate this buffer in many areas. For a change of the order of 3 °C or more, profound changes may be expected.

Expected impacts on phenology of vegetation

Further warming will shift the spring and summer phenology, i.e. bud burst, leaf development and flowering to earlier dates, while the impact on autumn phenology, i.e. leaf discoloration and leaf fall will depend on the possible effect of increased or more frequent drought on leaf senescence.

Expected impacts on the change in distribution areas of plants

A warmer climate should in general lead to a migration of plants to higher altitudes and to the establishment of new species at lower altitudes. As tree shift to new areas in general requires sufficient light and space, mortality of the existing trees is usually a precondition of migration. Therefore, it is very unlikely that a future shift in species area will occur gradually, but rather as a result of forest disturbance (Wohlgemuth et al. 2008).

A large number of models predict a shift of tree species in Switzerland ranging from gap models (Bugmann 1995) to climate envelope models (Guisan & Zimmermann 2000, Zimmermann & Bugmann 2008). In the more extreme, but not unrealistic climate scenarios (A1, IPCC), the overlap between current and future tree species composition is small for many sites.

Expected impacts on insect pathology and distribution areas

Increasing temperature should further increase the potential of population growth of insects and their capacity to shift to higher altitude. Whether wetter winter climate will affect the populations of fungi or insects is not yet known.

Changes in productivity

The climate scenarios with decreasing summer precipitation and increased temperature, particularly during summer, suggest a decrease in tree growth on sites with limited water storage capacity and low precipitation. At sites with high precipitation and low temperatures during the growing season, tree growth is expected to increase in the future, for example at high altitude. In addition, inter-specific competition will change as new climate-site conditions arise, leading to long-term changes in tree species composition. This will also change site productivity.

At dry sites trees may reach their ecological limit as warming continues and precipitation declines. In a reverse experiment a mature dry Scots pine forest in the area affected by pine decline has been irrigated, beginning in 2003 and doubling the amount of annual precipitation from 650 to more than 1300 mm. After only three years of irrigation, foliage amount has significantly increased as a result of increased needle length and longer shoots (Brunner et al. 2009, Dobbertin et al. in review). While fine root production has only slightly changed (Brunner et al. 2009), tree growth has almost doubled (Dobbertin et al. in review). Growing season of the stem wood has been prolonged due to irrigation contributing to the increased growth.

Expected impacts on disturbances and extreme events

The possibly increased frequency of drought would make trees more susceptible to attacks of those insects and pathogens that rely on weakened trees (Engesser et al. 2008). Leaf or needle eating or sucking insects and certain fungi that rely on well-developed foliage are not likely to profit from drought events.

It is still not clear if winter storms will increase in central Europe as a function of future warming or not (Fuhrer et al. 2007). Therefore, the potential of subsequent bark beetle outbreak following winter storms is difficult to evaluate.

2.3 Impact monitoring

A large-scale network of climate and precipitation stations is maintained in Switzerland by MeteoSuisse, including twelve homogenized stations going back to the year 1864 (Begert et al. 2005).

Several monitoring networks for forest and its reaction to climate change exist in Switzerland. Most are operated by the Swiss Research Institute for Forest, Snow and Landscape Research (WSL). The National Forest Inventory (NFI) has been repeated every 10 years starting in 1983 (Brassel & Brändli 1999, Brändli & Cioldi 2009) on a 1x1 km grid and since 1993 on half of the original plots. Currently, the NFI is changing to an annual rotating inventory, where the same plots are assessed every 10 years and annually one tenth of the plots are assessed. The NFI assesses the status and change in Swiss forests using detailed tree and stand variables and a limited number of site variables.

A subset of the NFI is annually assessed for tree crown condition, including crown defoliation, discoloration and damage causes, mortality, removal and ingrowth as part of the international ICP Forest Network. At an international level, this subset is called level I grid, while in Switzerland it is known as the Sanasilva inventory. The grid has been reduced from an original 4x4 km grid via an 8x8 km to a 16x16 km grid.

Since 1994, 18 long-term forest research plots as part of ICP forests were installed (these level II plots are called long-term forest research plots, abbreviated LWF, Innes 1995, Cherubini & Innes 2000). These plots were chosen to represent all major regions and forest types in Switzerland. All the mandatory measurements of the ICP Forests manual are carried out on these plots. The LWF sites usually include one climate station in the open field and one below canopy, where relevant climate parameters are continuously recorded. On 11 of these sites soil matrix potential has been measured bi-weekly and 5 sites are equipped with automatic soil water content measurements. Tree growth is assessed every 5 years on all trees and annually on a subset of trees. Crown condition and mortality are assessed annually on a subset of the trees, while ground vegetation, including regeneration, is assessed in irregular intervals. A network similar to the level II plots, with fewer parameters, and smaller but more plots, is run by the Institute for Plant Biology (www.iap.ch/english/english.html).

In addition, tree growth and mortality are measured in regular intervals of 5-15 years on about 300 long-term growth and yield plots in 133 sites (Zingg & Bachofen 1998) and on >170 permanent plots in >40 nature reserves, which are operated jointly by WSL and ETHZ (www.waldreservate.ch). Also, the Swiss Forest Protection service of WSL operates a competence centre at WSL with a data base of all biotic and partially non-biotic forest damage events. The data stem from local foresters or from WSL staff, and are verified by WSL staff (www.waldschutz.ch). The centre further disseminates information and offers consulting services. Finally, a forest fire database for Switzerland including all recorded forest fires is operated by the regional station of WSL in Bellinzona (Wohlgemuth et al. 2008).

It is currently planned at WSL to set up new monitoring plots along altitudinal gradients covering a range of temperature and precipitation regimes.

2.4 Impact management

As a consequence of several large-scale disturbances which have occurred since 1990, several handbooks for crisis management have been elaborated. In the field of forest management, storm is the most relevant disturbance agent. Therefore, a handbook for managing forest damage has already been published in a third improved version (BAFU 2008, in German). The handbook is divided into three parts dealing with management strategies at the federal level, operational guidelines for forestry professionals in the phase of crisis management and guidelines for restoration management on windthrow areas. Insect and pest outbreaks are recorded and managed by local forestry professionals. Floods, as one type of natural hazards, are managed with an integral risk management approach (Ammann et al. 2005).

3 Adaptation

3.1 Vulnerability of forests and forestry

In ecology, vulnerability refers to the severity, affected area and frequency of disturbances (mainly caused by storm, insects, forest fires and drought), and to the speed of recovery from disturbance (=resilience). Obviously, the general vulnerability is expected to increase with increasing warming. However, most forests in CH are seen as only moderately vulnerable to severe climate change impacts as long as the average increase in temperature does not reach +4-6 °C till 2100. The main reasons for this general assessment are:

- The tree species composition is relatively close to the (current) potential natural vegetation (NFI data); there are no large-scale plantations of exotic or unadapted tree species which are often highly vulnerable
- The tree species diversity is high. In 70% of forests, >1 tree species (dbh>12 cm) is present on plots of 500 m^2 size (NFI data)
- Sites at the limit to steppe climate are restricted to small areas (e.g., central Valais).

Despite the moderate vulnerability of most forests, forestry and in particular protective effects of forests may experience more severe impacts: If protection forests are heavily disturbed, their protective effect may be reduced. To restore effective protection and prevent damage, temporary defence structures which are very expensive may need to be built. Moreover, large-scale disturbances may also cause the release of carbon stored in the soil, and reduce the income of forest owners substantially. For biodiversity values, impacts can be positive or negative. While disturbances may cause losses in large old trees, they also promote plant diversity and may, by increased tree mortality, help to keep sparsely stocked forests with high species diversity relatively open.

Forests and forestry are probably more vulnerable to other external influences than climate change, such as the increasing use of forest biomass for energy.

It should not be overlooked that positive effects of climate change may occur, in particular in forest ecosystems where growth is limited by temperature. This is the case with many mountain forests. Higher increment in high altitudes may compensate for reduced increment in the lowlands.

3.2 General adaptation strategy or policy

An inter-departmental task force has been given the mandate to elaborate a cross-sectoral adaptation strategy for Switzerland (Küchli, oral communication). Already, a consistent biomass strategy was elaborated by the agricultural, land use, energy and environmental offices of the Swiss government and published in March 2009 (http://www.news-service.admin.ch/NSBSubscriber/message/de/26306). Other sectoral approaches are being developed for biodiversity, agriculture, energy from natural resources (in particular water), and natural hazards. A general assessment of climate change impacts was elaborated by scientific experts (OcCC 2008). Linkages of the mentioned sector approaches with the forestry sector are usually weak, and forest experts are often not adequately represented in bodies working on national strategies. Moreover, the effects of any national adaptation strategy or policy on the forest sector may be only moderate since much autonomy is with the cantons (see chapter 1).

3.3 Forest adaptation measures

At the national level no forest adaptation strategies or measures driven by the government exist. Guidelines for foresters and forest owners have been published in 4 cantons (Basel, Thurgau, St. Gallen, Zürich), and other cantons plan to follow.

Scientific experts have reviewed the state-of-knowledge about management options for adaptation and published the results in an extension journal (Rigling et al. 2008, Brang et al. 2008, Table 1). They tried to assign options to goals, and to estimate the time lag until these options become effective on a large scale.

Table 1. Silvicultural management options for coping with climate change, and associated goals. *Italics: Strategic options.* In the table, the time lag until an option becomes effective on a large scale is indicated in three classes (<20 years, 20-50 years, >50 years). Source: Brang et al. 2008.

Management option	Goal		
	Promoting adaptive capacity	Increasing resistance to disturbance	Reducing negative impacts
1. *Sensitivity classification of stands and sites*	20-50	<20	<20
2. *Adapted target species composition*	20-50	>50	>50
3. *Choice of silvicultural system*	20-50	>50	<20
4. Increased artificial regeneration	20-50	>50	
5. Adapted tending	20-50	>50	
6. Adapted thinning	20-50	<20	
7. Adapted final cuts	20-50		
8. Premature felling		<20	<20
9. Increased wildfire prevention		<20	<20
10. Reduction of ungulate impact	<20	>50	

3.4 Research studies on forest adaptation

The most important ongoing national projects with a forest adaptation component are:

- 'Mountland' (2008-2011, Sustainable land-use practices in mountain regions: Integrative analysis of ecosystem dynamics under global change, socio-economic impacts and policy implications) http://www.cces.ethz.ch/projects/sulu/MOUNTLAND
- Roof experiment in Valais in which drought effects on germination and small seedlings of different tree species are studied (2008-2011)
- 'Grisons forests in a changing climate', in which drought effects on trees in mountain forests are studied along altitudinal gradients (2009-2011)
- 'Drought resistance of endemic and exotic tree species', in which drought resistance of selected tree species (including exotic tree species) in Switzerland shall be ranked, based on past reactions of these species to droughts (2009-2012)
- 'Beech Regeneration: Testing Mediterranean Provenances in Swiss Beech Forests'. Project at Bern University of Applied Sciences SHL/BFH, on behalf of the COST Action FP0703 ECHOES.

- Tending mixed natural post-windthrow stands in the young growth and thicket stage in which the influence of tending interventions on tree species diversity is studied (2002-2011)

A large research program 'Forests and climate change', co-financed by the Federal Office of the Environment and the Swiss Federal Research Institute WSL, was launched in March 2009 (www.wsl.ch/forschung/forschungsprogramme/target). 16 projects have been funded. [to be completed as soon as funded projects are known, end of September 2009]

4 Mitigation

4.1 Swiss Carbon Account

In Switzerland, carbon storage in forests has increased by 52.270 Gg CO_2 equivalents since 1990, mainly due to spread of forests in high altitudes and increase in growing stock. Annual balances in carbon retention differ substantially, mainly due to extreme events (Fig. 5). The economic conditions and social developments make it less appealing to farmers to maintain pastures in rather poorly reachable mountain areas. The increasing forests are from natural regeneration and not managed. Swiss forests now cover 1270 km^2 (31% of the country), an increment of 4.9% in 11 years (LFI 3). In the Swiss Alps, forest area increased by 9%. Another reason is a rise in growing stock, again mostly in mountainous areas. Discussions about taking into account the carbon stock in harvested wood products and a generally wider view on climate protection in the forestry sector are going on.

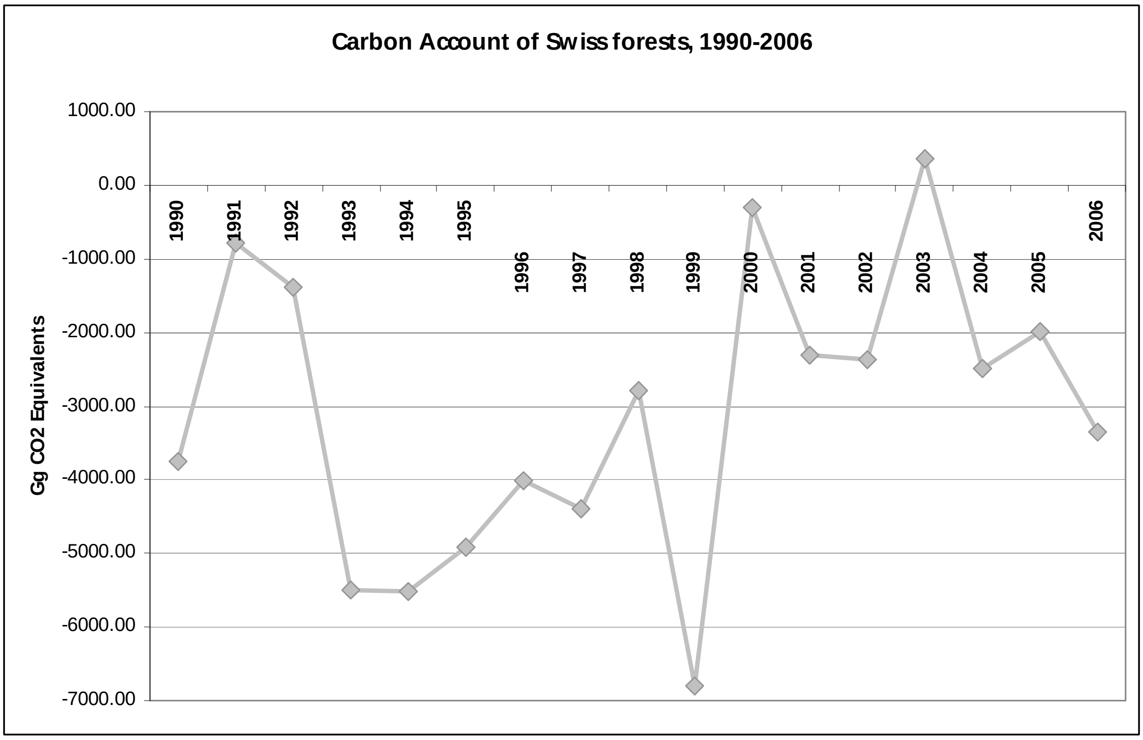

Fig. 5. GHG emissions for the Swiss forest sector in Gg CO_2 (http://unfccc.int). Negative emissions correspond to sequestration.

4.2 Political processes, instruments and strategies for mitigation

Switzerland is obliged by the Kyoto Protocol to decrease greenhouse gas (GHG) emissions by 8% or approx. 4 Mio. tons CO_2 eq/year in the average of the years 2008-2012 compared to 1990. It is currently discussed to find an agency with representatives from various stakeholders of Swiss forestry, the so called 'Agentur Wald', to assess centralised data on carbon sinks or sources, and to deal with possible income through CO_2 certificates (Schmidtke 2006, Fischlin 2008). The main challenge is to define if and how the income through carbon sinks will be paid back to the forest owners.

In Switzerland, there is no national plan to sequester a certain amount of CO_2 in forests by taking specific measures. However, there is a law to protect the forest area. Newly established forests are legally considered as part of the forest area and cannot be deforested anymore, except under special conditions, e.g. in construction zones (dynamic forest definition). Apart from that, increase in forest area is a purely passive process that leads to an accumulation of CO_2 in Swiss forests.

Outside forests, there are several programs to decrease CO_2 emissions. The CO_2 Act establishes a broad framework for measures designed to reduce CO_2 emissions. Most CO_2 emissions are energy related. The CO_2 Act is fully compatible with energy policy approaches such as the Energy Act and the related energy efficiency programs ('SwissEnergy' action plan). Examples of measures are a tax on CO_2 emissions on heating fuels, incentives to private companies to reduce emissions (i.e. Stiftung Klimarappen, Energieagentur der Wirtschaft), promotion of renewable energies (SwissEnergy action plan), regional programs and a national program to refurbish buildings (Nationales Gebäudesanierungsprogramm).

Besides, research on the contribution to GHG of natural soils, swamps, cattle and agriculture as a whole is underway. At the moment, with the exception of emissions from transportation, the Kyoto goals are considered to be reached, including contributions from forests / carbons sinks and CDM certificates.

4.3 Forestry as a source of bio-energy

The Swiss government has set a goal to increase renewable energy production by 5'400 GWh by 2030 compared to 1990 (Office of Energy BFE). The mostly publicly owned energy providers have to include this statement in their strategies. Wood energy is interesting for economic reasons and due to wide societal acceptance. Annual timber harvests are increasing, also due to a promotion of wood as an environment friendly material for building.

Forestry as a source of bio-energy is hence becoming more important, but also raises some questions. In the context of a new subsidy system, large quantities of wood will be burnt in combined heat and power stations (SwissEnergy). In a first stage, most of the raw material will be waste wood. But considering the amount of material needed to feed the planned power stations, fresh wood from forests will become more important as a source of energy. This wood is not available anymore for other material uses. The Office of the Environment has therefore developed a concept, called 'Cascading Model' (Kaskadennutzung) which imposes the first use of wood in construction, before burning and converting it to energy (Hofer et al. 2007). This concept is publicly discussed and has no legal status at the moment.

Besides the use in combined heat and power stations, the Paul Scherrer Institute (PSI) is doing research on gasification of wood residues (SNG gas). First pilot plants are in operation. The option to use SNG gas in large scale plants is politically discussed and also considered by large energy providers.

Traditionally, energy wood is used on the country side in small firings to heat private buildings. Recently, large numbers of wood chip ovens are installed to heat public buildings or even whole quarters, using wood residues from local forests. Pellet ovens are getting more popular with private house owners. Most of these firings replace heating systems previously furnished with fuel oil.

Overall, doubts are rising if the demand of all existing and planned wood power stations and sawmills will not exceed the sustainable growth of Swiss forests which is estimated at 9.5 Mio. m^3 by the national forest inventory (LFI 3).

4.4 Research studies on mitigation

4.4.1 CO2-effects of forestry and wood industry

Hofer et al. (2007) argue that minimizing CO_2 emissions can be done in three ways: Storing carbon in wood products, using the sink function of forests, and substituting fossil fuels. In different scenarios they analyse options of future CO_2 politics for forestry and wood industry. The scenarios mainly view different ways of forest management and their respective amounts of wood output. Having calculated the CO_2-effect of four different scenarios ('Baseline', 'Maximizing annual growth', 'Maximizing carbon storage', 'Reducing forestry measures') the authors see the highest decrease in CO_2 emissions if wood utilisation is optimised: Wood should be sequentially used in construction (building purposes) and afterwards energy production ('Cascading model'). Additionally, the results show just narrow potentials by using the Swiss forests as CO_2 sinks. In the short term, sinks are considerable, but in the long term the forests will become CO_2 sources again.

4.4.2 Calculation method for the Greenhouse Gas Inventory

Thürig et al. (2008) introduce the GHGI-method of calculating the CO_2 flows in Swiss forests, in order to get realistic estimates. Using data from various sources (national forest inventory, national forestry statistics, annual climate data etc.), the method enables calculating the sink effect of different forest types. Annual storage amounts and losses are cross-counted and multiplied by CO_2 factors at different stages.

4.4.3 Accounting for forest management in Switzerland

Schmidtke et al. (2006) point out that every nation decides on how to handle carbon storage. The authors advise to remunerate forest owners according to their efforts to contribute to reaching national Kyoto targets.

Carbon storage will become a new function of Swiss forests. Their owners must be enabled to decide on how to implement the provision of this environmental service into the holistic entity of forest management.

The Federal Office for the Environment FOEN organised a workshop on Article 3.4 of the Kyoto Protocol in 2006. Three ways to deal with forestry sink-certificates are identified: The Federation claims them for itself, the certificates belong to forest owners, or the Federation buys the certificates as additional emission rights from forest owners. One way to manage CO_2 certificates would be the creation of a CO_2 agency for forest and wood management. The process of mapping the potential as a carbon sink of every single forest area nationwide would be time and cost intensive. Therefore, there is a consensus to assemble a CO_2 agency to centralise data assessment and evaluation. In order to assure a minimum effort by the forest owner, legal standards for a CO_2 friendly 'forest management' are needed. The costs to meet these additional requirements can either be compensated according to sink performance, measures taken or by becoming participators of the agency and benefiting from its profits.

4.4.4 Fact sheet on forest management to increase carbon sinks

Thürig et al. (2008) develop scenarios to calculate the effects of different management models with respect to carbon storage:

- Reduced timber harvesting: Tremendous carbon storage potential within 80 years
- Kyoto optimised: Carbon storage gaining within 90 years
- Maximisation of annual growth: Carbon storage within 50 years, with a following small decrease and a continuous increase after
- Advanced production: Carbon emission through reduction of living and dead wood in forest

Three of the four scenarios can perform carbon savings, but the sink potential is limited. In any case there is a potential for at most 90 years. Afterwards, the forests will act as carbon sources again.

4.4.5 Carbon sinks: A prospect for the forest sector

Volz (2008) calculates that if Switzerland utilises its whole forests' sink potential, the national reduction obligation will decrease from 8% to 4.5%. From 2012 on, it might be possible to account for wood products in the Kyoto Protocol. The emission trade market could emerge as a new business for forest owners. Calculations for four forest enterprises yield earnings from carbon sinks of 6 to 71 CHF/ha and year.

4.4.6 Carbon sink capacity of Swiss forests

Wolf (2008) states that every forest has only a limited potential of carbon storage. After a while, forests become carbon sources again. In Switzerland, as well as in the surrounding Alpine countries, forests will on average stay carbon sinks for another 90 years. Then their storage ability will be saturated and carbon will be emitted. The duration mainly depends on the type of forest management. Besides, climate change will have an influence on the sink potential. Three models are used to estimate the potential of Swiss forests as carbon sinks. The calculations are based on three National Forest Inventories from 1983 to 2007. Each model predicts a rebound to carbon sources around the year 2100.

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