5 Vulnerability analysis, impact on climate and adaptation to climate change

5.1 Expected effects of climate change

The third IPCC assessment of climate change concludes that there is increasing evidence that man is affecting the global climate system.[1] The mean global temperature has risen by approximately 0.6°C over the last hundred years; in Europe the mean temperature has risen by about 0.8°C during the same period. The 1990s was the warmest decade so far recorded in Europe.[2] Sweden has become warmer and wetter over the last 140 years. However, from a more detailed perspective, fluctuations have been downwards as well as up. The rise in temperature has been most evident in spring. All seasons are wetter, except for summer, which does not display a clear trend. As for extreme weather conditions, such as cold, heat, heavy precipitation in a single day and storms, there may be a tendency for more maximum temperature records and fewer minimum records to have been set in recent decades. Otherwise, it difficult to see any lasting changes.[3]

The global scenarios for economic, technological and social development and accompanying emissions of greenhouse gases, together with land-use changes, have formed the basis for IPCC assessments of future climate change and its impact on man and the environment. Taking into account the sensitivity of various climate models to changes in concentrations of greenhouse gases, the IPCC thinks that the mean global temperature may have risen by a further 1.4 - 5.8°C by 2100.

The global climate change scenarios also indicate major impacts on the hydrological cycle, which are expected to become more intensive. However, regional and local effects on climate may differ considerably from the mean global figures. In some regions the risk of flooding will increase; in others there will be a greater risk of drought. Nor can surprises or sudden changes in global or regional climate systems be ruled out. If the Gulf Stream weakens, which a number of model calculations suggest will happen over the next hundred years or so, the effect on the climate of northern Europe will be grave indeed, and all land (and water) use in the region would be severely affected.[4] Assessment of a given country's vulnerability to climate change must also be made in relation to other expected changes in the natural and human environment, also taking account of uncertainties.

According to the IPCC, vulnerability is "the extent to which a natural or societal system may incur damage caused by climate change". Vulnerability depends on the systems's sensitivity and ability to adapt. Vulnerability analyses are intended to illustrate potential future damage. Social, economic, cultural, environmental and other conditions may have changed when the future arrives. The time frame of a vulnerability analysis may vary of course – the further ahead we look, the more uncertain our forecasts will be.

Sweden's Second National Communication under the Climate Convention presented impacts and vulnerability to climate change. Those assessments were based on the first assessments of expected impact on climate in Sweden and focused on the impact on technical systems, corrosion, hydrological systems, geotechnical systems and the energy system. Most of those assessments were of a general nature; for the Third National Communication they have been extended to cover more areas and provide a more detailed assessment.

The analysis of vulnerability to climate change is based on the SWECLIM climate scenarios, developed at the Rossby Centre at the Swedish Meteorological and Hydrological Institute (SMHI). The analysis also takes some account of important long-term changes in the natural environment, such as acidification and eutrophication/nitrogen saturation of soil and water, as well as certain social factors such as demographic trends. Many assessments of Sweden's vulnerability to climate change are therefore more qualitative and descriptive, rather than purely quantitative.

5.1.1 Basis for vulnerability analyses – SWECLIM climate scenarios

Analyses of the vulnerability of society or of natural ecosystems to climate change is essential for effective

[1] Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 2001

[2] Assessment of Potential Effects and Adaptations for Climate Change Europe: The Europe ACACIA Project. 2000

[3] Effekter och sårbarhet av klimatförändringar i Sverige ("Impacts of, and vulnerability to, climate change in Sweden"). Swedish EPA Part of report 5171, 2001

[4] Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of WorkingGroup II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 2001

measures to control emissions and adjustment plans. A proper description of future climate conditions is needed as a basis. Global climate simulations like those summarised by the IPCC, for example, form the basis for Sweden's climate scenarios for the Nordic region and Sweden. Since 1997, this has been carried out as part of the SWECLIM programme, in which the Rossby Centre at SMHI has developed an advanced regional climate model system (see also Chapter 7). The system has been used to make detailed studies of the potential impact of global climate change (as predicted by global climate models) on the climate of the Nordic region. A key advantage of regional calculations is that a considerably higher level of detail can be used in the calculations and that typical regional features, such as the Baltic Sea, river systems, lake systems and the mountain chain can be described more realistically. Regional features influence the simulated climate and may give rise to locally important feedback to a general climate trend. The regional simulation only covers a small part of the globe and must therefore be run in parallel with the large-scale climate trend predicted using global climate models.

The same technique is commonly used in regional weather forecasting, eg, by national weather services.

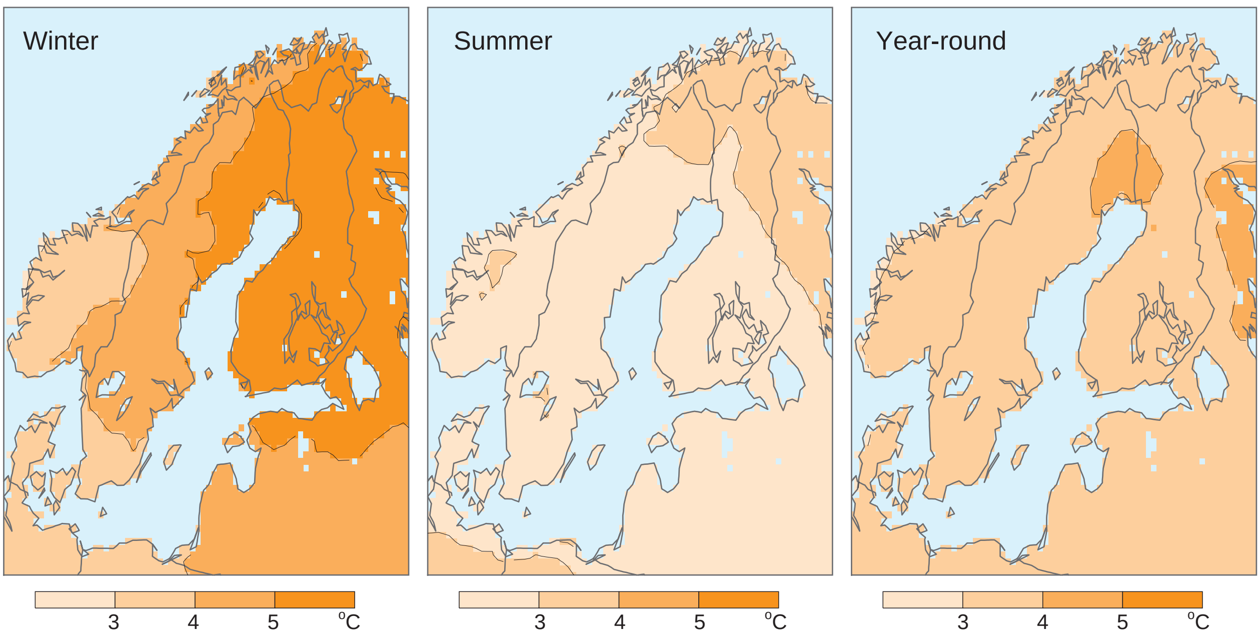
The latest IPCC assessment shows that when the entire range of emission scenarios is examined using a number of climate models, the mean global temperature is expected to have risen by a further 1.4 - 5.8°C between 1990 and 2100. The range given in the previous assessment in 1995, which assumed more extensive future emissions of sulphur, was 1 – 3.5°C. SWECLIM has based its approach on two global climate scenarios, one from the Hadley Centre at the UK Meteorological Office at Bracknell, Berkshire in the UK, and the other from the Max-Planck-Institut für Meteorologie in Hamburg, Germany. Both these centres are engaged in advanced climate modelling. SWECLIM has based its scenarios on two 10-year periods from each centre. In both cases, one of the two periods is used as a control, representing "no climate change", ie, current climate conditions. The other period represents a degree of future climate change. The basis for the SWECLIM scenarios is an increase in the content of greenhouse gases in the atmosphere (expressed as carbon dioxide equivalent emissions) of 100 – 150 per cent, and a rise in the mean global temperature of 2.6°C. The latest IPCC report indicates that this rise may occur in 50 to 150 years. The time horizon in the SWECLIM scenarios can therefore be simplified and expressed as "in 100 years". In this time frame, the regional scenarios do not appear to be extreme assumptions; rather they are representative of a central result based on the estimates in the various emission scenarios and climate models of climate sensitivity.

Summary of important results – temperature and growing season

The Nordic climate is considered more sensitive to emissions than is the global climate as a whole.

[5] Albedo (Latin): the proportion of incoming radiation reflected by a surface, here the earth's surface.

Figure 5.1 Increase in mean temperature in the SWECLIM regional climate scenarios "in 100 years". Warming in the area is somewhat higher to the north and east than along the Atlantic coast in the west and in the south



Source: SWECLIM/SMHI

Although most terrestrial areas are expected to heat up more than marine areas, this effect is exacerbated in northern Europe by a feedback effect via albedo[5] as a result of the effect of warming on winter snow cover and sea ice. Another typical feature of the area is uncertainty as to future changes in thermohaline circulation in the Atlantic Ocean and of the route taken by storms, as well as possible changes in the configuration of atmospheric circulation patterns. It is also assumed that emissions of sulphur, which produce airborne sulphurous particles that create a cooling effect, will decline further in the future.

The regional scenarios suggest that the mean annual temperature in Sweden will change by about 4°C. This is over 40 per cent more than the mean global change of the underlying calculations. The mean winter temperature is expected to rise somewhat more, by 4 – 5°C. The rise in summer is expected to be somewhat lower, 2 - 3°C (see Figure 5.1).

Temperature changes affect various climate variables and processes. Evaporation is affected by temperature, for example. Seasonal snow and sea ice are also affected by temperature. One central parameter in impact analyses is the length of the growing season. The regional scenarios predict that this will be prolonged by 1 – 2 months in Sweden. This will affect forests and agriculture, among other things.

An initial analysis has also been made of extremes of temperature, even though 10-year simulations of current climate and climate "in 100 years" are much too short to make representative analyses of them. However, results show that whereas annual maximum temperatures will be raised about as much as the mean change in summer (2 - 3°C), there will be a substantial rise in annual minimum temperatures, as compared with the mean change in winter temperature (see Figure 5.2).

Precipitation and evaporation

The regional climate scenarios suggest there will be significant changes in precipitation and evaporation in the region in the future. Figure 5.3 shows results for mean annual precipitation (P) and net precipitation/evaporation (P-E). The latter is an approximate measure of available water for the formation of aquifers, soil moisture and drainage into watercourses. The greatest increases in both precipitation (P) and Precipitation-evaportion (P-E) are along the Atlantic coast and in northern Scandinavia. A slight decline is predicted in south-eastern Sweden, however. Annual changes in precipitation of over 10 per cent are significant compared with modelled natural variability. Significant changes occur in the west and north. Moreover, P-E reacts with greater relative increases in the north and a decrease in the south-east. Precipitation increases more than evaporation in the north; the contrary applies in the south-east. When the analysis is performed for different seasons, the result is that the northern increase in precipitation and precipitation-evaporation becomes substantially greater in the autumn. But the indications of drier conditions are clear and more widespread in southern Sweden in summer.

As with temperature, changes in certain extremes have been analysed in the regional scenarios. Heavy precipitation, eg, the average maximum annual precipitation over 24 hours, is expected to increase in the

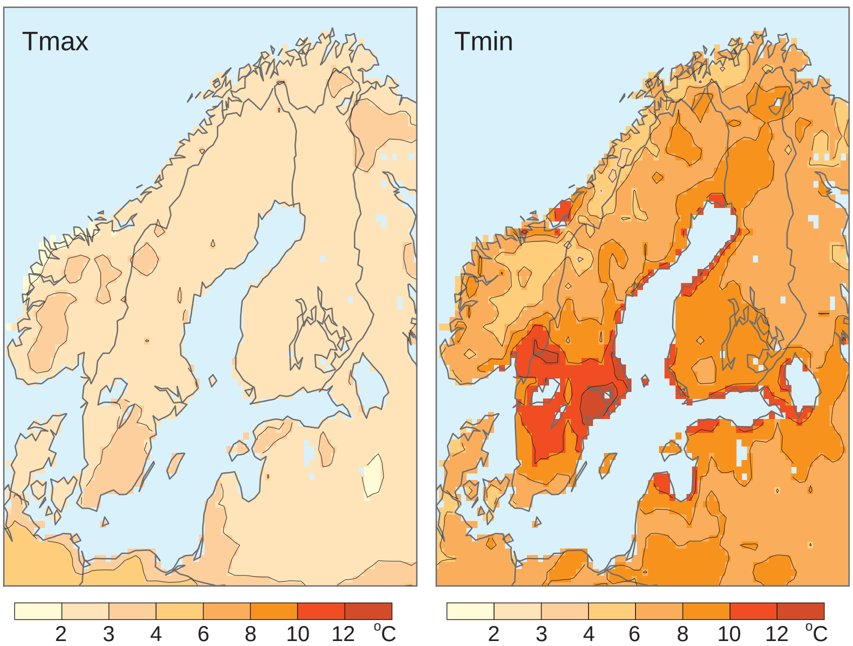


Figure 5.2
Estimated average changes in annual maximum temperature (Tmax) and minimum temperature (Tmin)

Source: SWECLIM/SMHI

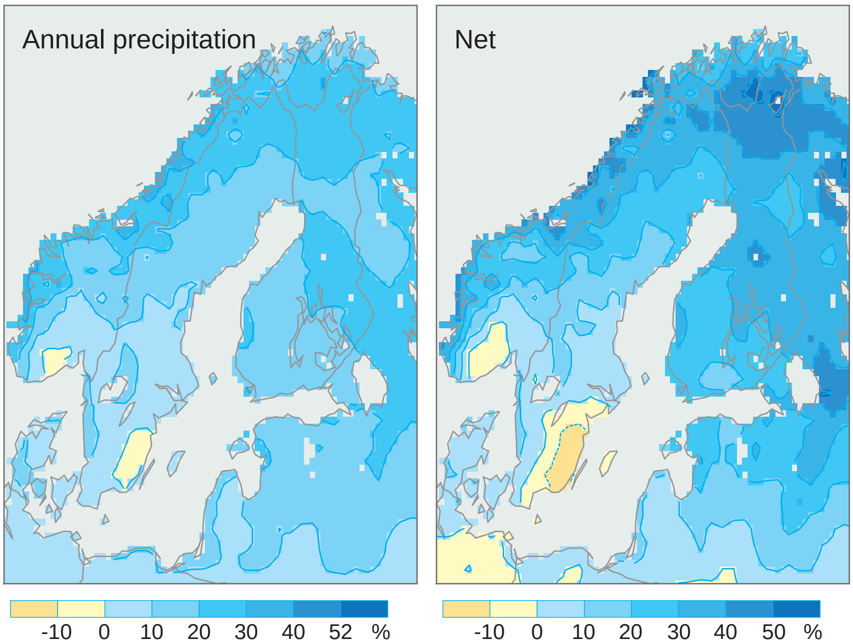


Figure 5.3
Estimated regional scenario changes in mean annual precipitation (P) and net precipitation/evaporation (P-E)

Source: SWECLIM/SMHI

region, in areas both where mean precipitation rises and where it falls.

Wind

The regional climate scenarios suggest moderate changes in ground-level winds. There is some increase in coastal regions, out to sea and over large lakes, where ice cover will diminish on average. Increases in specific areas are a few per cent up to 10 – 15 per cent at most. Changes in wind speeds in summer are expected to be limited. There are some indications of moderate increases in mean wind speed in montane areas in autumn.

However, the fairly short regional climate simulations performed to date only provide a basis for limited conclusions as to wind changes. Possible changes in extreme weather conditions, such as storms, have not yet been studied.

Snow

Higher temperatures will cause the snow cover to shrink, notwithstanding increased precipitation over

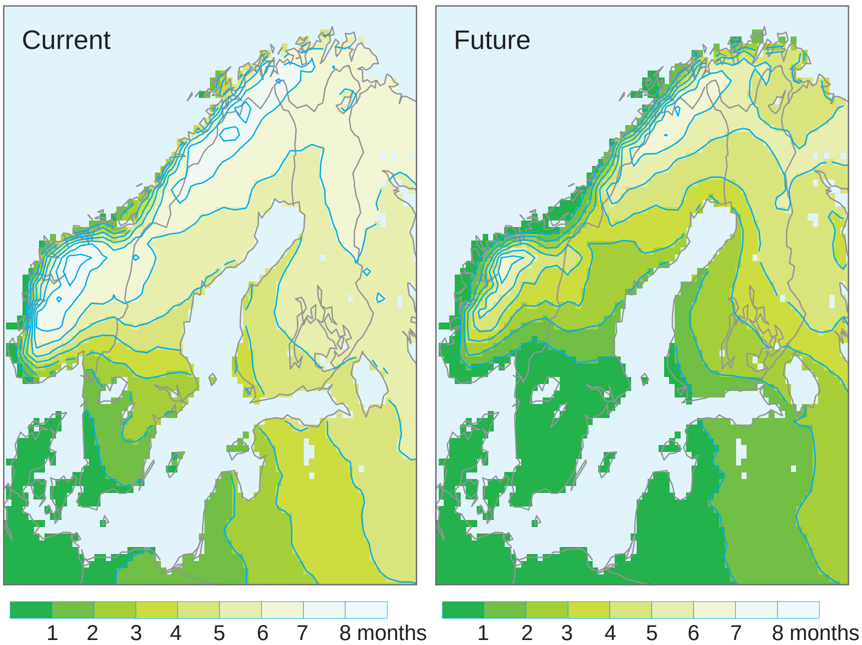


Figure 5.4
Average period of snow cover during the year in the region according to the scenarios. The current simulation (on the left) represents typical conditions during the most recent normal climate period (1961 – 1990). The map on the right shows results from the regional scenarios.

Source: SWECLIM/SMHI

large areas. The snow season is shorter and maximum snow depth less throughout Sweden in the SWECLIM scenarios (see Figure 5.4). The effect on the depth to which the ground freezes is a more complicated issue. Higher temperatures will reduce this depth where there are snow-free surfaces, such as roads. A thinner snow cover over snow-covered surfaces may have the opposite effect, because the ground beneath the snow will be less well insulated from the atmosphere. Here, the ground may freeze to a greater depth, despite higher winter temperatures.

Water resources

SWECLIM has also translated the regional climate scenarios into water resource scenarios, using separate hydrological modelling. These scenarios have been produced both for various areas of Sweden, and for the entire Baltic catchment area. The estimated changes in water supply largely conform to the changes in precipitation-evaporation: increased water supply in the north, but no clear change or a fall in the south. One important conclusion to date is that the characteristic spring flood of today will be more irregular and less intense, on average. This is because the snow period will be shorter and the snow depth less due to the warming effect. However, the water supply is expected to increase in winter and also in autumn as a result of heavier precipitation. Accordingly, the risk of flooding will diminish in spring but increase in late summer and autumn, particularly in the north. The scenarios are considered to be most uncertain in relation to central parts of the country, in the transitional zone between the increase in the north and the tendency towards a decrease in the south.

Drainage into the Baltic will also be affected. The scenarios indicate that the quantity of fresh water entering the Baltic will increase in the north but be less affected, or perhaps decrease, in the south. Here too, the differences between the seasons will become less pronounced.

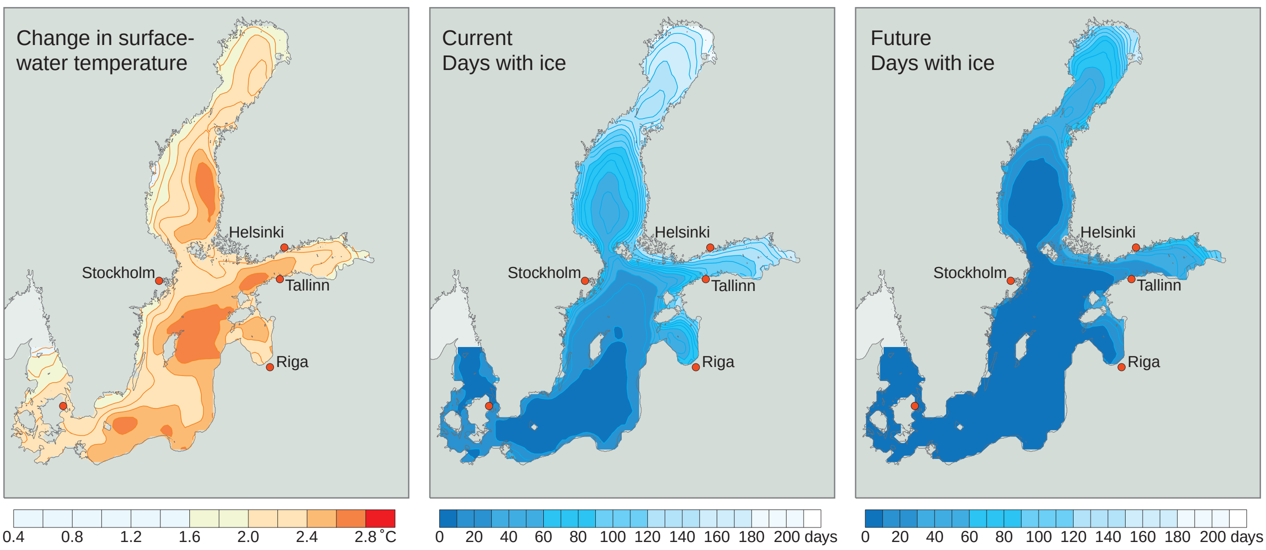
The Baltic Sea

The SWECLIM regional modelling system also includes models for the regional sea, the Baltic, which is too small to be realistically represented in current global climate models.

Regional warming will naturally affect the Baltic. The surface layer of the sea will warm up down to the halocline. The latest scenario calculations suggest that warming will be greatest in the north in summer but greatest in the south in winter and spring. According to the calculations, the depth of the halocline and thermocline will not be substantially altered. In addition to temperature changes, the impact of wind on mixing and the impact of saltwater intrusions on Baltic salinity may cause changes in the stratification of the water column. On an annual basis, the sea surface will warm up by a maximum of just under 3°C.

At different times of the year local temperature changes of up to 4°C or slightly more may occur. Circulation effects ("upwelling" and "downwelling") will cause large variations in water warming to occur between different parts of the Baltic. Regional warming will greatly ameliorate average wintertime ice conditions

Figure 5.5
Estimated regional scenario changes in the surface temperature of the Baltic Sea, on an annual basis (left). Mean number of days with ice in a regional Baltic simulation. Current conditions (centre) and "in 100 years" (right).



Source: SWECLIM/SMHI

in the Baltic (see Figure 5.5). The scenarios indicate that ice will be confined to parts of the Bay of Bothnia and far into the Gulf of Finland in a normal year.

The increasing precipitation in much of the Baltic catchment area will generate more fresh water, which will affect the Baltic. There may also be somewhat less drainage into the Baltic from southerly catchments. More fresh water may have a dilutive effect, thereby reducing salinity. However, the critical factor governing salinity is the frequency and size of saltwater intrusions from the North Sea. These inflows and outflows are driven from the atmosphere and might also be affected by drainage. Changes in these driving forces may occur, but this has not yet been studied in the regional scenarios.

Warmer seas around globe will raise the level of the oceans as the warmer water expands.

Melting continental glaciers outside the Antarctic will also add to this effect. The global rise has been estimated at an average of 9 – 88 cm by 2100, compared with 1990. Even if the mean global temperature rise stabilises, it is believed that sea levels will continue to rise for a long time owing to the enormous inertia of the oceans. Estimates of regional changes in sea level calculated in global models are more uncertain; changes may be non-existent or double the average. For example, global simulations give contradictory indications for the level of the North Sea. However, a SWECLIM study suggests that the level of the Baltic will closely follow that of the North Sea. Hence, a rise there will be accompanied by a similar rise in the Baltic.

The SWECLIM regional scenarios provide a basis for vulnerability analyses, and they are used to give a regional description of the impact of future regional climate change. In addition to scenarios showing mean changes, it is important to obtain better background data on potential changes in variability and extremes. Further quantification of the uncertainty in scenarios is also important to enable the results to be used in societal planning.

5.1.2 Other factors affecting vulnerability to climate change

Natural ecosystems changes as a result of physical factors, such as land use, and chemical factors, such as deposition of acidifying and eutrophying substances. Ecosystems are also inherently dynamic, as when one species replaces another, for example. This may impact on the sensitivity and vulnerability of the natural environment. As for man, developments in a given society depends on national policy as well as events in the outside world. Sweden and other small countries engaged in free trade with the rest of the world are greatly affected by events in the world around us. Swedish membership of the EU is a particular factor affecting vulnerability. Assessments of vulnerability in the event of climate change are therefore heavily dependent on the way these other factors develop alongside climate change.

Changes in the natural environment

Acid deposition has reduced pH in lakes and watercourses and has caused serious damage, such as loss of plant and animal species. Nearly 17,000 of Sweden's 95,000 lakes are affected by acid deposition. Many of them have seen their pH fall by 1 point. Some 10,000 lakes have therefore been limed to counter the adverse effects.

Deposition over forests has also lowered pH in our forest soils, which increases the risk that metals, such as aluminium, will leach out and harm the biota. But acid deposition has also affected soil nutrient balance. Important base cations such as potassium and magnesium ions have leached out of forest soils. Some weak soils in south-western Sweden have lost almost their entire reserves of available base cations. This has damaged the ecosystem. Forestry also affects the store of base cations and other nutrients in the soil.

Acid deposition has declined throughout much of Sweden following reduced emissions in Sweden and Europe as a whole. However, deposition has not yet fallen to a level where no harm is done to ecosystems, known as the "critical load" of acidifying substances. Soil recovery is a very slow process, one that also has a great influence on the rate of recovery in lakes and watercourses. Acidification will therefore persist for a very long time; only the areas least sensitive to acidification will recover within 50 to 100 years.

The input of nutrients such as nitrogen and phosphorus to lakes, watercourses, seas and soils has a major impact on ecosystems. Growth in northern ecosystems is often limited by a lack of nutrients. Greater availability of these substances therefore produces a dramatic increase in biomass. Lakes, watercourses and coastal regions become overgrown and undergo dramatic changes in flora and fauna. A greater supply of organic matter often results in oxygen deficiency on lake and sea beds, particularly in the Baltic. The main reason for the excessive nutrient levels in lakes, watercourses and other waters is leaching from agricultural land and input via waste water. Some steps have been taken to reduce these discharges. But the store of nutrients in lake and marine sediments is sufficient to maintain a high nutrient level in the water for a long time to come, in most cases for many decades, and in some instances for several centuries.

For forest soils and other soils on which fertiliser is not used, atmospheric deposition is a major source of nitrogen. the supply of nutrients encourages biomass growth in forest and soil. When the soil becomes nitrogen saturated, some will leach into lakes and water-courses, and finally into coastal waters. The effects of this nutrient supply may persist for several decades after supply has ceased.

Changes in society

The sensitivity and vulnerability of society to climate change depends very largely on societal development. Welfare in a country like Sweden depends on external as well as internal factors. An important internal factor is population growth or decline, which influences aspects of socio-economic development, such as the construction of new housing, educational needs, health care and family structure. The current ageing population trend in Sweden is expected to continue for at least another 25 years. Economic theory predicts that demographic changes of this kind result in less saving, high inflation and low growth.

Environmental and climate issues may then be given lower priority owing to a lack of resources. Thus, future demographic trends may impact vulnerability to climate change and the ability to take steps by reducing emissions of greenhouse gases and adapting various sectors of society to the effects of climate change

Crises and conflicts may arise within or between countries, where a shortage of food or other vital resources caused by climate change may be one of many factors. A shortage of resources may exacerbate an existing crisis caused by migration and economic decline, for example.

Trade, economies and transport are becoming increasingly global. It is therefore likely that crises and conflicts in the world around us will have a decisive effect on Sweden. Thus, we must adopt a global view of risk and security, a view that integrates features of social, economic and ecologically sustainable development.

5.2 Vulnerability analysis

The climate and weather we have today can have a major impact on the Swedish environment and society, particularly when it comes to infrastructure. Violent storms, often in combination with high water levels, cause particular damage. The vulnerability analysis for the various sectors is based on current weather phenomena that may seriously harm the environment and society. This information has then been combined with climate scenarios and other societal and environmental factors. This analysis shows that fairly uncommon and extreme weather phenomena, such as high winds and flooding, have the greatest significance in terms of vulnerability. However, there is an element of vulnerability in slow, long-term changes in mean values, such as mean annual temperatures and annual precipitation; these factors have been included in the analysis.

There is a considerable degree of uncertainty, both in the scenarios and in the vulnerability analysis. This is because there is a still a lack of basic knowledge about the effects of climate change on society and ecosystems, and also because it cannot be ruled out that sudden rapid changes or surprises may occur in climate, the environment and society.

5.2.1 Water resources

Generally speaking, Sweden has a plentiful supply of good quality water. Water quantity or quality may be lacking in dry years in some parts of southern Sweden and on the islands of Öland and Gotland. A very high proportion of drinking water comes from surface sources, ie, lakes and watercourses.

In the SWECLIM scenarios, a warmer, wetter climate will increase water supply in the north, whereas in southern Sweden the effect may be less water supply in some cases and more in others. There will also be a general effect on seasonal distribution, with more water supply in winter and an earlier but less severe spring flood. Water supply may become more extreme in autumn, particularly in northern and central Sweden, with a greater risk of flooding. The larger water supply during this period will also exacerbate leaching of nutrients such as nitrates and ammonium nitrogen, which are highly mobile.

A study of the entire Baltic catchment gives a broader perspective on the issue of climate and water resources. The area covers approximately 1.7 million square kilometres[6] and includes 14 countries. A study has shown how drainage into the various basins of the Baltic may change "in 100 years" according to the SWECLIM climate scenarios. The effect will be a dramatic change in the annual rhythm of flow in rivers and increased drainage from the north of the region. This will naturally have a major impact on Baltic salinity, nutrient supply and hence the ecosystem.

Changes in water flow in regulated watercourses will also greatly affect electricity generation in the country, perhaps offering potential for greater and more even production.

However, restrictions on water levels in dams, reservoirs and aquifers and on flow rates imposed by current and future water court judgments, which are intended to reduce risks and protect other interests,

[6] Rummukainen, M., et al., 2000

may limit the scope for more hydropower. The increased flow in our regulated watercourses may increase the risk of dam breaches, since they were built to withstand the vagaries of the climate as it is at present.

Higher lake temperatures may greatly affect drinking water quality in terms of taste, odour and colour. There will be a greater risk of infectious diseases and toxins spreading if flooding upstream spills out pollutants into lakes and watercourses used for drinking water supply. Water supply infrastructure has a very long lifespan and is vulnerable to climate change: a long-term strategy to reduce vulnerability must therefore assure alternative sources of water supply, particularly aquifers. The south and south-east of the country are particularly vulnerable in this respect.

High flow levels in watercourses and higher levels in lakes and watercourses affect shores physically and also affect their ecology. Regulation of flow and water levels can to some extent counter the adverse affects of high flow and high levels.

To sum up, water resources are, to a degree, vulnerable to climate change, particularly in southern Sweden, where water shortages may occur in dry years. Hydropower dams and other dams may also become more vulnerable.

5.2.2 Land and soil

Climate change, involving changes in temperature and hydrology, affects biological, chemical and physical processes in soil. Several processes central to essential ecosystem functions are dependent on these soil processes. Key processes include mineralisation of organic matter, which releases important nutrients and alters soil structure, weathering of minerals, which releases trace elements (including calcium, magnesium and potassium) but also causes leaching of soluble substances. These essential functions also form the basis for sustainable agriculture and forestry. If there is more water in the soil, its structure may deteriorate as a result of ploughing (in autumn, for example); which may affect essential functions in agricultural soils. Increased drainage from forest soils may accelerate leaching of important minerals and lead to the formation of podsols.

Land and soil can also be affected by a greater presence of sea salt if the climate becomes more maritime. These effects are expected to be significant in coastal areas.

Higher soil temperatures accelerate decomposition of organic litter, although warmer and wetter conditions will increase biomass production in many ecosystems. The balance between these two processes: decomposition and supply of organic matter, affects the quantity of organic carbon in the soil. Temperature is a factor limiting decomposition of organic matter and mineralisation in many boreal, subarctic and alpine ecosystems. Growth in these ecosystems may also be limited by climate factors. Climate change is expected to increase the rate of turnover of organic matter, but it is not clear whether the overall effect will result in a net accumulation or net decomposition of organic matter. The SWECLIM climate scenarios indicate a large net effect in Swedish forest soils. Estimates suggest that nearly 14 Mtonnes of carbon dioxide could be taken up in soils annually "in 100 years".

Water supply and hydrology are also important factors influencing soil structure and stability. A rising water table, increased drainage into lakes and watercourses and higher flow rates in water courses may increase the risk of landslip and subsidence. Several valleys, including Klarälven and Göta Älv, have soil strata comprising marine clay deposits ("quick clay"). Saturation and mechanical movements in these strata cause extensive landslip.

The Swedish land mass has risen rapidly since the last ice age. This land elevation continues in northern and central Sweden, whereas a slight depression of the land is occurring in the far south of the country. If the mean sea level rises in the region, some land would therefore be lost. The southernmost coast of Sweden is particularly vulnerable because the combination of wave movements, strong currents and a rising sea level will rapidly lead to coastal erosion there, since the soil often comprises loose deposits such as sand. Coastal erosion is already occurring and action has been taken to avoid further land loss. Southern coastal wetlands will also face the risk of being flooded by saltwater if the mean sea level rises.

Land and soil is potentially highly vulnerable to climate change because we do not know enough about the nature and extent of possible effects, and because it may be difficult to find efficient and cost-effective remedies.

5.2.3 Ecosystems

Scandinavian ecosystems are limited in their growth and species diversity by a number of factors, such as availability of nutrients, barriers to distribution and climate (eg, temperature and precipitation). The predominant ecotypes are temperate mixed forest (the nemo-boreal biome), coniferous forest (the boreal biome), and subarctic ecosystems (the subarctic-alpine biome). Much of our biodiversity is found in lakes and watercourses close to these terrestrial ecosystems. This biodiversity may be affected by climate change. The Baltic may be regarded as a separate, brackish, ecosystem, whereas the Kattegat and Skagerrak form part of the larger North Sea and North Atlantic Ocean. Extreme conditions also have a great impact on biodiversity. In particular, the low winter temperatures may determine whether or not many species survive in Sweden.

The SWECLIM scenarios indicate that climate change may have a dramatic impact on the Swedish environment. The rapid changes predicted in these scenarios include a rise in mean temperature of about 0.4°C per 10-year period. Precipitation is also forecast to rise by up to 2 per cent per decade. The climate zones determining the range of the various biomes may move north by 50 to 80 kilometres a decade. It is possible that conditions will allow entirely new ecosystems and biomes, such as temperate deciduous forests of oak and beech to predominate in southern Sweden. There may also be much greater potential for individual plant and animal species occurring south of Sweden to become established here.

However, there is a considerable time lag between the necessary changes in climatic conditions and establishment of a new ecosystem, particularly when it comes to ecosystems inhabited by species with a long reproductive cycle and/or little ability to increase their range.

The combined effects of climate change in increasing concentrations of carbon dioxide will affect primary biomass production. For example, it has been estimated that forest biomass production (wood) could theoretically double in southern Sweden and increase fourfold in northern Sweden if the shortage of nutrients did not limit growth.

Effects on the Baltic ecosystem are potentially dramatic. Temperature change has a direct impact on various species, as do changes in the extent of ice cover. Increased precipitation in the Baltic catchment area is expected to increase the supply of fresh water, which, if it is not counterbalanced by more frequent saltwater intrusions, may substantially reduce salinity.

An increased supply of water entering the Baltic is expected to increase nutrient input, particularly in the event of wetter autumn weather. However, a greater supply of water in the northern Baltic catchment and less in southern areas of the entire Baltic catchment may result in lower concentration of nutrients in the sea because most agriculture is in the south of the country. The overall effect could threaten marine species (eg, cod) and favour freshwater species (eg, perch, pike, zander (pike-perch) and cyprinids). There is a risk of non-native species spreading into the Baltic. The dynamics of algal blooms in the Baltic may also be affected. Lake fauna is expected to change; species tolerant of warmth (perch, pike and cyprinids) will benefit, but with changes in population dynamics, such as more rapid growth, earlier sexual maturity and shorter lifespans. Other species, typical of cold water, such as cisco and salmonids, will suffer and may disappear from shallow lakes and running waters in southern Sweden.

Higher temperatures are expected to allow a number of southerly species to become established on land (in terrestrial ecosystems), although there are also some obstacles to colonisation (the Baltic, the arable plains of southern Sweden). The spread of non-native species, which is currently inhibited by cold winters, may become a much more serious problem. Some endangered species of southerly origin may benefit from a warmer climate.

Other, more northerly, species and ecotypes may suffer seriously owing to a combination of warmer climate, more nitrogen leaching and the current high levels of atmospheric nitrogen deposition.

There is a very great risk that arctic-alpine species in subarctic-alpine areas of the Swedish mountains may become extinct, unable to compete with species favoured by greater warmth and nitrogen availability.

Wetlands

The term "wetlands" covers a fairly disparate group of ecosystems covering much of Sweden's surface area, which therefore represent important elements in the environment and are of great ecological value in terms of biodiversity and other criteria. The vulnerability of these systems ultimately depends on the way climate change effects hydrological characteristics, since wetlands by definition are areas with a high water table.

It should also be emphasised that relatively small hydrological changes in a wetland area may have a fairly major impact on its ecological processes, even though the change is not great enough to place the system outside the definition. However, the tools currently available are not sufficiently accurate to allow proper quantification of wetland vulnerability.

Nevertheless, on the basis of the SWECLIM scenarios, it may be inferred that vulnerability is particularly pronounced in relation to the distribution and occurrence of wetlands in those parts of southern Sweden where the water table may drop as a consequence of significantly less precipitation. In northern Sweden, on the other hand, vulnerability ought to be lower because of higher precipitation. Nor can it be ruled out that a damper climate in northern Sweden could increase the area of wetlands, topography allowing. Extreme seasonal fluctuations in water flow in watercourses and lakes may also render surrounding wetlands vulnerable as a result of changes in the hydrological dynamics.

The sensitivity of biodiversity in wetlands is particularly great in areas where these ecosystems are more isolated features of the landscape, since many species will then face an effective barrier to migration.

Peat bogs play an important part in the global carbon cycle. Accumulation of carbon in peat bogs is governed by a combination of temperature and hydrology and studies have shown that peat bogs can change from sinks of carbon to sources of this element from one year to another. In many cases this fluctuating pattern has been explained by annual variations in climate, which indicates that the carbon balance in these systems is heavily dependent on climate. However, the tools currently available are not accurate enough to allow proper quantification of this.

Sudden changes and surprises cannot be ruled out, which shows the need for long-term planning and a precautionary approach to conserve biomes, ecosystems and biodiversity.

Many complex processes related to biodiversity are important to man, but we nonetheless know little about their vulnerability to climate change. These include mycorrhiza-tree growth symbiosis, decomposition, fixing and release of substances in soil and water.

Seen as a whole, ecosystems are potentially highly vulnerable to climate change. The montane and Baltic ecosystems are particularly vulnerable. Other ecosystems are also potentially at risk because of the rapidity of climate change. Southern Sweden may see the arrival of completely new species, although barriers to migration will considerably delay their establishment. Man can help all these species by creating a "patchwork" landscape with a variety of microclimates within the migration range of the species. At present we do not know enough about the impact on wetland ecosystems or their vulnerability.

5.2.4 Forestry

Forest growth is governed by a number of factors. The main ones are water supply and nutrients, sunlight and the air and soil temperature. Each species is also subject to inherent limitations. The relative importance of the various determinants varies throughout Sweden.

In the north temperature and nutrient availability are often the limiting factors; in the south it is usually water supply.

There is currently net growth in Swedish forest biomass, which can be used for timber, pulp and other forest products. This net biomass growth is largely the result of earlier felling and planting of new trees, and the fact that a large proportion of forest is approaching maturity. Another contributory factor is atmospheric nitrogen deposition, since a shortage of this element often limits growth.

The primary production factor for photosynthesis and growth is the quantity of sunlight. According to the SWECLIM scenarios, the number of hours of annual sunlight may diminish somewhat if cloud cover increases. However, it seems more certain that the amount of sunlight during the growing season (when the temperature remains constantly above 5°C) will increase substantially. The sole reason for this is that the growing season will be about one month longer in spring as well as autumn. The effect of the longer growing season will be greatest in northern Sweden (a 15 – 18 per cent increase). The increase in the south will only be 9 - 12 per cent. The reason for this difference is that there is more sunlight to be gained, relatively speaking, from a longer growing season in northern Sweden than in the south.

At present water is not normally a factor limiting photosynthesis and growth in northern Sweden, but may be so in southern Sweden, particularly the south-east, where current water shortages during the growing season may reduce production by between 40 and 50 per cent some years. The SWECLIM scenarios suggest that water supply will increase by between 50 and 75 mm during the growing season in northern Sweden, whereas the latest scenarios indicate a decrease during the growing season in the south. Increased water supply in the north is unlikely to have an appreciable impact on production there. But lower water supply in the south will certainly reduce production on healthy soils. Spruce and deciduous trees would suffer more than pine, because they need more water. In the long term, an excessively wet climate may turn some productive forest land into boggy forest, which would reduce production. The SWECLIM scenarios indicate that this could be a problem in inland areas of northern Sweden, in particular.

The production of new shoots in spring by spruce, pine and most deciduous trees is affected by day length and air temperature. Higher air temperatures ought to mean that this process starts earlier. Using results from a large number of field experiments, where trees have been exposed to differing temperatures, and a simple simulation model to reflect shoot bursting, it has been concluded that this should occur about two weeks earlier in the south and about four weeks earlier in the north of Sweden. In some circumstances, this will involve a risk of frost damage. Frost damage may be serious in stands of saplings and young forests if frost occurs when shoots have begun to burst or immediately afterwards.

Saplings may die if they are exposed to spring frosts year after year. The frequency of spring frosts indicated by the SWECLIM scenarios has been compared with the estimate time for shoot bursting in a future climate. It was found that the risk of spring frosts did not seem to be any greater. However, more scenario data will be needed to make a better assessment of the effect of climate change on spring frost frequency.

Apart from the fact that production in Scandinavia is limited by the short growing season, it is also severely limited by a lack of nutrients in soil. Warmer soils resulting from climate change will increase biological activity in soil, which will affect decomposition of organic matter and recycling of important nutrients. A field experiment has been conducted in northern Sweden. Soil temperature has been raised 5°C over the natural level using electric cables. Tree nutrient status has improved and stemwood production has increased by over 100 per cent. Further experiments will reveal whether this production increase is a lasting one. As part of the same experiment, a study has been made of the way soil warming affects trees that already have optimum access to nutrients. Here, the production increase is much more modest – about 15 per cent higher than in soil at natural temperature. This increase can probably be ascribed to an earlier ground thaw and water availability in spring, which ultimately enables photosynthesis to start earlier.

Higher carbon dioxide levels over a period of hours to several months dramatically increases the rate of photosynthesis. However, after a time, the photosynthesising needles seem to adapt to the new levels and photosynthesis falls back to its rate under normal carbon dioxide conditions. Field experiments in northern Sweden, where entire trees have been exposed to elevated carbon dioxide levels for several years, have demonstrated a 10 to 15 per cent increase in photosynthesis. Further field experiments will reveal whether this effect is a lasting one, or whether it declines or increases once again.

Transpiration, unlike photosynthesis, releases carbon dioxide. This process is heavily dependent on temperature and increases greatly as temperature rises. The mean annual temperature is between 6 and 8°C in southern Sweden and between 0 and 4°C in the north. An increase of between 3 and 4°C will increase the cost of maintaining the function of living plant cells. Increased transpiration will cause more carbon dioxide to be emitted from living biomass, which may affect the overall carbon balance in Swedish forests. It was also found in the above soil warming experiments that transpiration from the heated soils did not rise; the soil seemed to adjust to the higher temperature and maintain the same level as the unheated soils.

A conservative estimate, based on the SWECLIM scenarios and including the above effects but not the effects of higher carbon dioxide concentrations and markedly higher nutrient turnover in the soil, is that production in Sweden could increase by between 10 and 20 per cent. In volume terms, annual growth in total volume over bark might increase by approximately 15 million cubic metres. At current growth and felling rates in Sweden, it is estimated that trees remove about 7,000 ktonnes of carbon each year (equivalent to carbon dioxide removal of approximately 26,000 ktonnes a year). Forest soils remove between 2,000 and 5,000 ktonnes carbon a year (equivalent to carbon dioxide removal of between approximately 7,000 and 18,000 ktonnes a year). The SWECLIM scenarios suggest that trees could eventually remove a further 4,000 - 5,000 ktonnes of carbon a year, ie, a total of 12,000 - 13,000 ktonnes of carbon a year. (The carbon balance in forest soils has not been included in this calculation). This forest removal can be seen in the context of Swedish carbon dioxide emissions from fossil fuels, which total 16,000 - 17,000 ktonnes of carbon per year.

A rise in productivity in submontane forests and higher tree lines will impact other important sectors and interests, such as outdoor leisure and tourism, reindeer husbandry, nature conservation and biodiversity.

Over the last 70 years four storms have caused significant windthrows; a total of 70 million cubic metres of stemwood has been blown down. The worst windthrows occurred in 1969, where about 37 million cubic metres of stemwood was felled. Windthrows occur when wind speeds reach full storm or hurricane force. There are no SWECLIM scenarios for increased storm frequency at present, but the question of extreme weather phenomena will be the subject of research. More frequent occurrence of these wind speeds would naturally cause problems for forestry. Large quantities of wet snow freezing onto tree branches can also cause trees to fall, particularly in windy conditions during or after the snowfall. Good forest management can mitigate the extent of storm damage.

A warmer and wetter climate with a longer growing season will extend the northerly limits of various tree species. This is likely to apply to many broadleaf species currently only found in southern Sweden. However, drier conditions during the growing season in southern Sweden may act to the detriment both of broadleaf species and spruce on healthy and damp soils.

Insect populations may also expand in a warmer climate with longer summers. Insect pests and other organisms harmful to trees display a clear north-south gradient. These include pine weevil, pine sawfly and honey fungus, which cause greater problems in southern Sweden. Some pests and diseases may move northwards and become more frequent. It is also conceivable that new parasites could become established in southern Sweden.

Overall, the SWECLIM scenarios indicate that Swedish forestry will produce substantially more wood and other forest products. It is conservatively estimated that productivity may rise by 10 to 20 per cent. Attacks by pests, insects, fungi and other pathogens are also expected to increase.

5.2.5 Agriculture[7]

Climate has an enormous impact on the quantity and quality of crops grown in Sweden.

Crop yields can vary greatly from year to year. These wide fluctuations are due to variations in precipitation, sunlight and temperature, as well as attacks by various pests, fungal diseases, insects, viruses and nematodes.

Not only quantity, but quality of crops is highly dependent on the weather. Grain crop quality can suffer greatly as a result of wet weather in late summer: often it will then only be of use as animal feed. Various fungal diseases can also increase the quantity of mycotoxins in grains, which will reduce the prospects of using the crop to make flour.

Potato crops may suffer from leaf and then tuber blight in wet summers, with a resulting drop in quality. Crops will be unusable some years.

A warmer and wetter climate over the coming 100 years will have a great impact on future crop production and also on the occurrence and distribution of various pests.

Current crop production and fluctuations in yield

There are currently about 2.7 million hectares of arable land in Sweden. The area of arable land and grazing land has declined over the last 50 years. This, in combination with rationalisation, greater field size and other factors, has changed the landscape.

An area of about 800,000 hectares has been under feed grain (mainly barley and oats) in recent years. Bread grain has taken up 400,000 hectares, potatoes 35,000 hectares, oil seed rape and turnip rape 50,000 hectares and sugar beet about 55,000 hectares. Much arable land comprises seeded grassland (about 35 per cent). The total annual value of crop production (including ley) may be estimated at SEK 12 – 14 billion, not including various forms of farming support, which total some SEK 3 – 4 billion.

Crop yields vary significantly from year to year and region to region owing to variations in precipitation, temperature, sunlight and other factors. Average spring barley yields have been 4,000 kg per hectare in recent years; autumn wheat yields have been about 6,000 kg per hectare. Yields vary greatly from year to year, however. In 1992 the spring barley yield was 2,000 kg per hectare in south-eastern Sweden. Hot, dry weather is likely to have been the main reason, although aphids may also have been a factor. Spring barley yields may fluctuate widely from year to year as a result of current weather variations: from 6,000 kg per hectare down to 2,000 kg per hectare. Other crop yields also vary a great deal.

Impact of climate change on cultivation

On the basis of the general correlation between temperature and natural vegetative production, crop yields could increase by 20 – 40 per cent if the mean temperature rises by about 3°C. But we may expect sizeable differences, depending on crop. By comparing current differences in crop statistics for various regions of Sweden with differences in temperature between these regions (ie, by moving entire regions north), it has been concluded that yields may increase dramatically in the Mälar valley region west of Stockholm. However, depending on the crop, yields per hectare may vary between a few per cent for rape to up to 30 per cent for cereals and 100 per cent for potatoes if the temperature rises by 2°C.

This method of extrapolation moves soil types, crop varieties and cultivation techniques northwards. In some cases this is a reasonable assumption, but the method may indicate too high an increase for potatoes. The relative extent of the areas over which various crops are grown must be taken into account in order to determine yield changes in Mälar valley region. If the distribution remains unchanged, the regional increase will be about 25 per cent. If the cultivation pattern changes to that currently prevailing in the far south of Sweden, however, the increase would be 55 per cent. Another factor is a possible change in the total area of arable land. The relative changes are expected to be generally greater in northern Sweden.

Simulations using dynamic soil-crop models for specific sites have been employed as an alternative to the above calculation method. These simulations also take into account changes in soil and water conditions and are essentially a projection of research findings in a future climate change scenario. If the temperature rises by 1.7°C, autumn wheat yields on clay soil in Uppsala (60 km north of Stockholm) are expected to increase by almost 20 per cent, but by under 10 per cent on sandy soils. Even though nitrogen mineralisation from the soil is expected to increase by about 20 per

[7] Jordbrukets känslighet och sårbarbet för klimatförändringar. ("Agriculture's sensitivity and vulnerability to climate change") Swedish EPA Report 5167, 2001

cent, the quantity of nitrogen in the crop rises by only a per cent or so, and even falls on sandy soils. These findings thus suggest that protein content might fall if fertiliser use remains constant and the climate changes.

There is much to suggest that crop yields will increase if climate change occurs as generally predicted by the climate models. The choice of crops is a highly significant factor governing the size of yield increase at regional level. Regional differences in climate also have an impact on crop size, as does soil type. These two factors also greatly influence potential changes in nitrogen leaching. It should be added that these conclusions assume that climate variability will remain as it is at present.

At higher temperatures, higher carbon dioxide levels and higher precipitation, most crop yields are likely to be higher than at present. It will also be possible to grow some crops, such as autumn wheat, autumn barley and autumn oil plants, further north. In parts of south-eastern Sweden, such as Kalmar county and the island of Öland, dry summers may cause greater variations in yield than is now the case. Potato crops may also be greatly affected if irrigation is not available.

It will be possible to grow some crops that require higher temperatures in the south of Sweden. Maize is one example; it will probably be cultivated more widely. It may also be possible to grow sunflowers, although here profitability will also be affected by factors other than purely biological aspects. It will also be possible to establish vineyards in the south of the country, although it is very difficult to assess their potential profitability.

Insect pests, plant diseases and weeds

As in other countries, various harmful insects, plant diseases and weeds may have a great economic impact in Sweden. It is estimated that damage to all Swedish crops may be reduced by 5 – 15 per cent using current cultivation methods and pesticide doses. Pesticide use currently costs about SEK 1 billion each year.

Infestations vary a great deal from year to year and from region to region. There are a number of reasons for this. Apart from cultivation techniques, choice of varieties and crops and varying degrees of resistance to pests, various weather factors may also have an impact.

Weather affects pests in several ways. Temperature, precipitation, humidity, sunlight, wind and snow cover influence the occurrence and range of various insect pests and plant diseases. Temperature affects insect life cycles, range and airborne activity. Fungi growth is also influenced by temperature, although their development is even more dependent on precipitation and humidity.

The wind also plays a major part in the spread of insects and spores of fungi. For example, aphids may be carried long distances on the wind. Infestations some years in the south-east of the country are the result of wind-borne aphids originating from the other side of the Baltic. Infestations of diamond-back moth in oil plants and brassicas in the eastern parts of central and northern Sweden in 1995 were caused by insects carried into the country on easterly or south-easterly winds. In the 1960s a fungal disease of wheat occurred for the first time in the south and south-east of Sweden. The spores may have entered the country with seed, but the most likely cause was airborne spores carried from the south-east of what was then the Soviet Union.

Effects of pests on crops in the event of climate change

A warmer and, in most places, wetter climate will favour a number of pests and diseases that attack various crops. These include fungal diseases, viral diseases, bacteria, nematodes and insects.

Aphids are likely to become a greater pest in Sweden. At present virtually all of them overwinter as eggs on various winter hosts. If the temperature rises by 3 – 4°C, most of them are likely to be able to overwinter on various crops and weeds, as is currently the case in Britain and the continent. Some 30 of the 500 plus species of aphids currently found in Sweden have an economic impact on crop yields. It is likely that several of them will become more important in terms of direct damage and also as carriers of various viral diseases.

Cereal dysentery virus, which is mainly spread by oat and grain aphids is only a moderate problem for spring cereals, but it is likely to become a greater threat, particularly to autumn cereals.

Viral diseases spread by aphids also affect oil plants, but these diseases currently pose little threat. Peach aphids, which carry viral diseases affecting autumn oil plants, will thrive in a warmer climate and will thus pose a greater threat to these crops.

Several cereal diseases that prefer a warmer climate will probably become more widespread. These include rust and mildew of grass. Higher precipitation will result in more cases of leaf spot fungi in cereals, eg, barley and wheat. The quality of bread grain may also deteriorate as a result of late summer rain. Wheat crops may be rejected for use as bread grain owing to lower falling numbers and more widespread occurrence of fusarium fungi. High concentrations of certain fungi on the grain may also increase mycotoxin concentration. Wet conditions also favour fungi such as ergot on cereals, which may render it unfit for eating.

Potato leaf blight and tuber blight are likely to become more common. Organic farmers will be particularly badly affected, since they cannot use pesticide to combat the disease.

Viral diseases of potatoes may also become more common, the most likely culprit being the peach aphid, which spreads leaf roll virus.

Several insect species not presently found in Sweden may become established in the south of the country. Examples include the Colorado beetle, which attacks potato crops in Germany, Poland the Baltic States and elsewhere. It may be carried by the wind to southern Sweden, where a warmer climate is unlikely to prevent it becoming established.

Fungal diseases like sclerotinia and black spot may become more prevalent among oil plants. As for insects, the cabbage stem flea beetle, which at present occurs mainly in the south of Sweden, may become more widespread. Sugar beet will probably be more frequently afflicted by certain viral diseases, particularly those spread by the peach aphid.

Effects and vulnerability in agriculture

Climate change as indicated by the SWECLIM scenarios is likely to increase some crop yields and allow cultivation of new crops in southern Sweden. The climate will also probably influence the occurrence and distribution of pests that attack various crops. Many pests and diseases are kept at fairly moderate levels by prevailing climate conditions. Pest increases can be combated by greater use of chemicals, but this is undesirable for other reasons, such as the harm they cause to flora and fauna, as well as contamination of streams and rivers, drinking water and groundwater. Greater efforts will probably have to be made to prevent infestation. Better cultivation techniques, increased use of resistant varieties and good crop rotation will therefore assume greater importance.

Organic farming will be particularly vulnerable to pests. In addition to the above preventive measures, production of virus-free seed will be essential. Use of biological methods will also increase. Notwithstanding preventive measures and steps taken during the growing season, shortages of organically grown produce will probably occur in years when pest infestations or inclement weather have occurred.

5.2.6 Fisheries

Plentiful fish stocks are largely dependent on policy, in which quotas, minimum sizes and protection of breeding areas are important factors in achieving sustainable fisheries.

Natural conditions, such as the status and supply of nutrients, as well as climate-related factors, are also important to the industry. The importance of the fishing industry in Sweden has declined over the last 30 years, one reason being the process of rationalisation that has taken place. Cod fishing in the Baltic, which is economically significant, has declined dramatically in recent decades; insufficient salinity and low levels of oxygen have inhibited cod reproduction. Lake fishing is also of some economic importance to the fishing industry, although nowadays most lake fishing takes the form of angling and other forms of leisure fishing.

Several models for general water circulation and climate change indicate a decline in thermohaline circulation in the North Atlantic and the Gulf Stream. This could have a decisive effect on fisheries in the eastern North Atlantic and hence on fisheries throughout Europe. Swedish coastal and Atlantic fisheries could also suffer as a result.

The Baltic Sea, Kattegat and Skagerrak

Climate change as indicated by the SWECLIM scenarios may cause widespread and radical changes in the ecosystems existing in the Baltic Sea, Kattegat and Skagerrak. The scenarios suggest less extensive ice cover in the Baltic and possibly a greater supply of nutrients from land. The increased flow of fresh water may affect salinity. However, the critical factor determining salinity is how climate change will affect the inflow of saltwater from the North Sea. This is currently an open question. In the scenarios, the surface water in the Baltic will be warmer, particularly in the north in summer and in the south in winter and spring. The period during which the water column is stratified will therefore be longer.

This will cause the thermocline to move downwards, which will reduce the living space available for species thriving at low temperatures. The longer period with stratified conditions increases the risk of oxygen deficiency in coastal waters, both at night close to the bottom in highly productive waters, and in areas of deep water that are isolated under the thermocline. These problems will also be exacerbated because less oxygen dissolves as water temperature rises, while the metabolic rate of organisms accelerates and oxygen consumption therefore increases. Warmer water is also considered to favour blooms of certain potentially toxic algae, eg, cyanobacteria. Lower salinity would reduce the occurrence of marine species – cod, turbot and plaice could disappear from the Baltic.

Reduced salinity may also eliminate crab and lobster from southern areas of the west coast.

Higher temperatures favour warm water fish, which, in the Baltic, may result in more rapid growth and possible larger populations of perch, pike and zander (pike-perch), particularly if salinity drops and suitable breeding areas are available. However, warmer water may be bad for cold water species, such as cod, whitefish, salmon and trout, at least in areas where they cannot compensate by moving into deeper water. Experience has shown that cold winters are good for flatfish recruitment; warmer winters may therefore reduce populations of plaice along the west coast.

Lakes and watercourses

A warmer climate "in 100 years" may be expected to have differing effects on fish assemblages, depending on depth conditions in their habitats. Generally speaking, the thermocline will develop earlier in spring and disappear later in autumn in a warmer climate. It will also occur at a greater depth. Major changes may therefore be expected in shallow lakes. Simulations indicate that typical cold water species in shallow lakes lose weight in summer if temperatures exceed the optimum. However, at even higher temperatures weight loss will cause the species to die out. Some cold water species will die out when there are no cool refuges available in summer.

Cold water species generally spawn in autumn; the roe does not hatch until spring. Stable, low winter temperatures are required if a good proportion of roe are to survive. It is therefore possible that ice-free conditions and a few degrees above zero may have an adverse effect on survival in southern Sweden.

The scenario "in 100 years" predicts that flow rates in water courses will change. The greatest risks in south-western Sweden are an excessive reduction in flow combined with high water temperatures. It is probable that cold water species like salmon and trout will disappear from many of watercourses in these areas. The main factor expected to affect conditions for fish in northern Sweden is a more constant flow rate. Many fish species undertake annual migrations, which are governed by, and dependent on, existing annual river drainage cycles. Spawning and fry development are also adapted to plankton production peaks occurring in conjunction with the spring and early summer floods, both in rivers themselves and in estuarine areas.

Increased precipitation may favour fish that spawn in fast-flowing streams, since these streams will be less inclined to dry up. If the temperature rise is not too great, this may benefit the sea trout, since its presence in coastal waters is largely dependent on reproduction in small streams, which now often dry up in summer.

Climate change as indicated by the SWECLIM scenarios may produce substantial effects on primary production, which may increase in most lakes, watercourse and adjacent marine areas. But the balance of species will also change, cold water species losing out to species that thrive in warmer conditions. Overall, fisheries in Swedish lakes and the Baltic Sea will become more vulnerable, particularly if overfishing is not prevented. The industry may be able to adjust to some extent by increasing its catches of species more tolerant of warmer conditions.

5.2.7 Transport, energy and industry

The vulnerability of the transport, energy and industrial sectors is largely dependent on socio-economic developments in these sectors. Infrastructure is sometimes built without sufficient account being taken of weather phenomena (high winds, extreme temperatures and heavy precipitation) that occur very rarely in our present climate. Long series of climate data can be reanalysed to provide a better basis for assessing sensitivity and vulnerability under present and future climate conditions. Vulnerability often arises when several factors interact or following a chain of events that are improbable under more normal conditions. Violent storms accompanied by wet snow may damage electricity distribution on local and regional grids, which will have a knock-on effect on transport, other energy supply and industry.

Transport

Hydrology influences the stability of roads, railway embankments and shipping lanes. Other climate factors, such as mean and maximum/minimum temperatures and wind conditions, also play a part.

Correct drainage is necessary to ensure that roads and railway embankments retain their carrying capacity. Carrying capacity depends on climate factors such as water availability, cold and heat, freezing and thawing processes, as well as type of soil. Silty soils, which are common in Sweden, cause particular problems. Parts of the national road network must be closed each year during the spring ground thaw because roads lose carrying capacity.

Some clay soils are prone to landslip. "Quick clay", which is deposited in saltwater, can suddenly become unstable when pore water pressure increases as the water table rises.

Entire sections of road embankment may then start moving. Landslip can also occur in running ground following heavy rain in conjunction with the spring ground thaw. Steep, sandy riverbanks may also fall or collapse because of undermining, internal destabilisation or heavier loads or vibration. Much of the road and rail network crosses clay and silty soils and requires special attention in connection with spatial planning.

Erosion of road embankments is a recurring problem around culverts, bridge supports and along ravines and upland stream beds. Erosion is ultimately caused by high water levels or heavy rain/snow, which may occur more often if the climate changes.

To some extent, transport is vulnerable for safety reasons limiting the use of bridges such as the recently opened Öresund Link in high winds. Frequent high winds exceeding the safety level may therefore cause more frequent disruption of traffic between Sweden and Denmark.

Extensive safety regulations govern bridge construction. Road building is not subject to anything like the same plethora of detailed regulations. Culverts, for example, can be highly sensitive to climate factors such as high water levels.

Energy

The SWECLIM scenarios suggest a high rate of flow in watercourses and hence increased potential for hydropower generation in Sweden. A higher mean temperature will reduce the need for energy to heat homes and commercial/industrial premises.

However, society will continue to become increasingly vulnerable to energy shortages, particularly shortages of electric energy. All our systems are directly or indirectly dependent on a reliable supply of electricity. An acute energy shortage, perhaps resulting from a breakdown in distribution, will rapidly cause secondary effects in all other systems, such as telecommunications, water supply, sewage treatment and transport systems. This will paralyse society.

Perhaps socio-economic and technical developments are the factors most increasing our vulnerability to energy shortages. Climate change may exacerbate this. Vulnerability engendered by climate change will mainly relate to extreme weather phenomena, such as high winds, heavy rain or snow and extreme cold. The scenarios indicate that extreme cold will become less common in the future, whereas the trend for high precipitation and strong winds is less certain.

Some of the effects and vulnerability to climate change can be combated by making the energy supply system more robust and increasing safety margins.

Industry

Manufacturing industry is particularly vulnerable to disruptions in supply of energy and raw materials. Swedish manufacturing industry is largely dependent on a supply of domestic raw materials from forestry and mining. However, increasing globalisation of trade and industry renders Swedish industry more dependent on the outside world.

On balance, a more reliable supply of energy in all sectors is the most important way of reducing society-'s vulnerability. Climate change may affect the energy supply system, particularly if extremely high winds and heavy precipitation become more common.

5.2.8 Health

Global climate change will affect health in various ways. Heat waves, storms, floods and weather-related landslip affect health directly, whereas changes in seasonal climate harm health indirectly by their impact on terrestrial and marine ecosystems.[8] Regional food production and water supply will be affected, supply probably improving in northern temperate zones and deteriorating in areas already hard hit. Rising sea levels will increase the risk of flooding, salt water contamination of water supplies and offer new breeding grounds for disease-carrying insects. Low-lying, densely populated areas, such as the Ganges delta and Po valley, are particularly at risk. These changes may lead to massive migratory movements, entailing everything from epidemics to armed conflicts. In global terms, adverse health effects will predominate, although some diseases may abate or disappear locally because conditions are too dry or wet or hot.[9] Cold-related health problems may become less common.

The risk of climate change causing health effects in a given area depends on a number of factors. Obviously, the degree of regional climate change is one key factor. But biological, logistical and socio-economic conditions are also significant. Biologically speaking, the vulnerability of different areas varies depending on the function and structure of local ecosystems, and the state of health and genetic susceptibility and immunity of the local population. The vulnerability of various constructions, road networks and electricity grids, sanitary systems and health sector capacity are of especial interest in emergencies. The socio-economic and technical capacity of a local community to take immediate and long-term remedial measures will be crucial in determining whether potential effects will in fact occur.

Effects in Sweden

From a socio-economic and technical viewpoint, Sweden is well equipped to take adequate remedial action. To do this in time, it is essential to identify potential climate-related health effects in various parts of the country.

Heat waves increase the incidence of deaths and illness due to cardiovascular and pulmonary disease.[10] The SWECLIM scenarios have not yet examined the

[8] Epstein 1999

[9] Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 2001

[10] For example, Jendritsky et al., In press

effect of future heat waves. Annual maximum temperatures are expected to rise about as much as the mean summer temperature, ie, by about 3°C. Lengthy periods of very high temperatures, ie, heat waves, must be studied in greater detail.

On the other hand, winters are expected to be considerably milder throughout the country, which will reduce the number of cold-related conditions, such as frostbite and angina. The SWECLIM scenarios indicate a slight increase in wind speed and a greater risk of flooding throughout the year. In addition to the risk of physical injury, this may cause contamination of drinking water and outbreaks of disease. For example, leptospirosis, which is spread by rats, has been found to increase after flooding in central Europe, when these rodents are flushed out of their burrows.[11]

There will be a greater risk of diseases of this kind spreading in Sweden if floods become more common.

Swedish summer temperatures are not expected to increase as much as those in winter. But urban air quality may still be affected. Moreover, ground-level ozone forms more readily at higher temperatures. Furthermore, the combination of air pollution and higher temperatures exacerbates respiratory problems.[12] Air pollution is also suspected of exacerbating hay fever by causing nasal blockage, which increases membranal pollen accumulation.

The growing season is expected to be prolonged by 1 – 2 months, which will affect both the distribution of various pollen-producing species and the length of the pollen season. Hot and wet summers and autumn seasons will prolong pollen production. This will add to the risk of several types of pollen being present in the air simultaneously, with an accompanying risk of more severe attacks. Higher concentrations of carbon dioxide in the air will, in itself, also increase production of certain kinds of pollen.[13]

Mould, fungi and mites might also thrive indoors in a warmer and wetter Swedish climate. This would in turn affect the frequency of allergies.

Water quality is affected not only by contamination by particles, soil organisms and saltwater from flooding and rising seas. Diseases spread by water and food, such as salmonella and campylobacter tend to be seasonal in their occurrence. Higher temperatures could lead to outbreaks starting earlier in the season and persisting longer. A correlation has been identified between outbreaks of cryptospirosis and giardia and heavy rain in Great Britain and the USA.[14] The effect in Sweden has not yet been studied.

The SWECLIM scenarios for Sweden, with milder winters, increased precipitation, earlier springs and later autumns create ideal conditions for harmful insects and animals. Flies, cockroaches and rodents spread contagion. Diarrhoeic illnesses (caused by E. coli) may therefore increase at certain times of the year. Rodents also provide a natural reservoir of blood containing a number of infections, which can be transmitted to man in their urine and faeces, by fleas on their fur or, as is more common in Sweden, by blood-sucking carriers like mosquitoes and ticks.

Vector-borne diseases

Borrelia is the most common vector-borne disease in temperate regions of the northern hemisphere, including Sweden. Infection is spread by blood-sucking ticks from rodents (and other animals) to man. Ticks also spread other diseases, such as TBE (tick-borne encephalitis) and erlichiosis. Ixodes ricinus, a disease-carrying tick species, has been the subject of particular study in Sweden in relation to climate change. Milder winters and warmer early and late summer nights since the mid-1980s have enabled this tick, which lives for up to three years, to spread northwards in Sweden along rivers and the north Swedish coast.[15] Central Sweden has witnessed a substantial increase in tick numbers during this period, which has been explained by a significant correlation between milder winters and a longer growing season – conditions that increase year-to-year survival rates among ticks and their hosts alike. Southern Sweden has not yet been studied in this context. The increase in TBE cases in Stockholm county during the same period has also been found to be related to shifts in the seasons. In a milder climate, ticks could become increasingly common, even in the north of the country. Ticks are potential carriers of numerous infections. Climate change could allow the spread of new diseases and possibly also enable new tick species to survive in Sweden. It is very difficult to reduce the number of ticks occurring naturally; efforts must instead concentrate on identifying new risk areas, informing the public how to avoid being bitten and developing vaccines where possible, as in the case of borrelia, for example.

Mosquitoes spread a number of diseases. Malarial mosquitoes are still found in half the livestock buildings in the southern and central areas of Sweden, although there is little risk of contracting malaria here.[16] Early treatment prevents further spread of the disease, since malaria only occurs in man and mosquitoes, not in

[11] Kriz et al., 1998

[12] Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 2001

[13] For example, Ziska & Caulfield, 2000

[14] For example, Rose et al., 2000

[15] Lindgren et al., 2000

[16] Jaenson, 1998

other animals. But the mosquito population may increase in a warmer and wetter climate. Thus, if malaria mosquitoes are present, someone who has been infected abroad could have time to cause a short-lived local epidemic before receiving treatment. Malaria is expected to become more common in Europe, as are other mosquito-borne diseases, such as leishmaniasis and certain kinds of encephalitis, like West Nile fever.[17] Tropical diseases like dengue fever might also spread to the far south of the country. With the exception of West Nile fever, there is little risk of these diseases gaining a foothold in Sweden. However, the number of people returning to Sweden having contracted these diseases abroad will rise. This will make greater demands of Swedish hospital and medical personnel. The range of mosquito and midge species in Sweden and their relative abundance will probably change. More insects will survive in a milder climate. Increased precipitation in parts of south and central Sweden may create new wetland areas, which will offer more breeding grounds. These may diminish in the north as a result of less widespread frozen ground conditions. New species may also become established. For example, reproduction of one particular disease-bearing mosquito is dependent on flooding. We need to know more in order to identify the diseases transmitted by insects that may be spread in various parts of the country owing to climate change.

To sum up, climate change may cause health effects in Sweden, but the country is considered to have the resources to prevent many of the epidemic diseases that may become more widespread. Training and information should be supplied to medical personnel to help them in their diagnosis, treatment and prevention of these new diseases.

5.2.9 Coastal zones

A large proportion of Swedish cities, town, villages and important factories are situated in coastal regions. These coastal zones are also environmentally important due to the biodiversity on land and in water. Coastal zones are also important spawning grounds for many fish species. These zones are affected by a number of climate-dependent factors such as wind, water level and the supply of nutrients entering the sea.

Climate change as indicated by the SWECLIM scenarios would produce a warmer and rainier climate. SWECLIM does not yet offer an unequivocal assessment of future weather variability. More violent and more frequent storms, and greater short-term variations in temperature and precipitation are quite likely to be the result of climate change.

Impact on coastal waters

In the scenarios, the surface water in the Baltic will be warmer, particularly in the north in summer and in the south in winter and spring.

Warmer winters will reduce the period of ice cover. There will probably be no ice cover along the west coast and the ice season in the Baltic proper will be much shorter. However, it is predicted that the Bothnian Bay, at least, will normally be covered with ice in winter in the scenario "in 100 years".

Warmer winters are expected to create more even flows in streams and rivers because wintertime precipitation will not accumulate as a deep, long-lasting snow cover; it will drain away fairly quickly. However, more rain and snow is expected, with more freshwater draining into the Baltic, particularly in the north of the catchment. If it is not counterbalanced by an increased frequency of saltwater intrusions, the considerably higher mean annual freshwater supply entering the Baltic will reduce salinity there. A sensitivity study of this suggests that salinity in the Baltic proper could fall to the levels currently prevailing in the Bothnian Bay. These predictions are obviously highly uncertain. For example, no adjustment has been made to take account of the fact that a rising sea level may create the right conditions for influxes of saltwater into the Baltic. However, there is a well-established historical correlation between accumulated precipitation in the Baltic catchment area and the salinity of the Baltic Sea.

Effects on biodiversity

One of the greatest threats facing terrestrial biodiversity is the northward shift of climate zones, which many organisms will find it difficult to keep pace with. The majority of marine organisms may be expected to find this much less of a problem, since they can travel long distances with the help of marine currents. The most dramatic effect of predicted climate change over the next hundred years will arguably be the consequences of higher precipitation. Many marine organisms are highly sensitive to even a slight fall in salinity and may become extinct across much of their range. Only at very low levels of salinity will the number of freshwater species begin to increase. This change may be particularly dramatic in the Baltic proper. If salinity there falls to 0.3 – 0.4 per cent, the common sea mussel, bladderwrack, cod and perhaps even sprat will disappear. With no common mussels, eiders will decline or disappear altogether. Salinity may also fall in the Kattegat and Skagerrak, and certain marine organisms suffer a decline, if the Baltic surface current along the west coast of Sweden will be stronger and

[17] Martens et al., 1997; Kuhn, 1997

more heavily diluted by freshwater. Warmer conditions will probably enable some southerly species to increase in numbers or become established in Swedish waters, provided that they can tolerate brackish conditions.

For example, oyster farming may become economically viable in south-western Sweden, since oysters can withstand fairly low salinity, while requiring high summer temperatures.

Mullet is a popular feature of the cuisine in countries further south in Europe. It has hitherto been recorded in the warm water off the coast close to the Ringhals nuclear power plant in south-western Sweden, but may become more common if the Kattegat and Skagerrak become warmer. However, Sweden may become host to species highly detrimental to our interests as well as those with culinary appeal. One example worth mentioning is Mnemiopsis leydyi, a North American species of jellyfish that feeds on zooplankton and fish fry. Its introduction in the Black Sea in the 1980s caused a crisis in the fishing industry there. The species has recently reached the Caspian Sea. However, it needs such high temperatures to reproduce that there is little risk at present of it invading the Baltic. But if the temperature of the Baltic rises as now predicted, an invasion might be possible.

Eutrophication and production conditions

As already pointed out, warmer summers will probably prolong stratification of the water column, which, per se, increases the risk of oxygen deficiency in coastal waters, an effect exacerbated by an increased nutrient load. Unless effective countermeasures are taken, a longer frost-free season and increased precipitation will most likely increase nitrogen leaching from agricultural land, although phosphorus leaching may decrease.

At present, availability of nitrogen (or lack of it) is the factor limiting growth across much of the Baltic, and so increased nitrogen leaching may be expected to exacerbate eutrophication. However, if nitrogen emissions increase while phosphorus emissions fall, the area of the Baltic where nitrogen availability limits growth may decrease, which may reduce blooms of nitrogen-fixing cyanobacteria. Since these are a natural feature of Baltic ecology, their disappearance would fundamentally reshape Baltic ecosystems. One result might be a change in the Baltic production season, with an earlier and perhaps more extensive spring bloom, but less production during the summer. Since the summer production provides food for herring and cod fry in the form of tiny zooplankton, a change of this kind could have an adverse effect on recruitment of these species. A heavier spring bloom could exacerbate oxygen deficiency in deep Baltic waters, since the organic matter thus produced normally sinks much more rapidly to the bottom in spring than it does in summer and autumn.

Since some species of nitrogen-fixing cyanobacteria may be toxic, the disappearance of large-scale blooms of this kind may also be positive for man. But if this were to occur, they would probably become more common in the Kattegat instead, where they are currently uncommon because of the higher salinity there.

5.2.10 Montane areas

Climate change in montane areas would cause the various ecosystem zones and species to shift upwards or downwards since temperatures fall with increasing altitude. A rise in the mean temperature of 4°C would cause climate zones to move almost 700 metres higher up.

This would mean that many subarctic, often low-growing, species (such as lichens and mosses) would lose out and be replaced by other, often higher-growing, species that require more warmth (such as bushes and trees). Higher temperatures mean increased biological and chemical decomposition of organic matter and a greater supply of nutrients, at least for a short time. This would benefit species that require more nitrogen. The overall effect is expected to be that the tree line would move higher up the mountain side. However, submontane forest is also dependent on favourable conditions over a number of consecutive years so that young plants can germinate and survive the most vulnerable stages of their development. Landslides and avalanches also influence the extent to which new ecosystems such as forest can become established. Existing montane forest may become denser owing to increased nutrient supply and higher temperatures.

Changing conditions in the ecosystem will also affect reindeer husbandry, which will suffer if lichens become less common in the mountains as the slopes are colonised by bushes, and sparse submontane woodlands become denser.

In addition to effects on biological systems, hydrological processes will change. Ground freezing will be affected; in some areas the ground will freeze to greater depths if the protective winter snow cover is thinner. Frozen ground may be less widespread in some areas where the snow cover comes later. The presence of water in soil affects physical soil processes in mountainous areas. Lengthy periods with temperatures above zero degree celsius and more precipitation may cause more landslip and more serious landslides.

Overall, mountainous regions like those in Sweden are highly sensitive and vulnerable to climate change. Several ecosystems such as the alpine-subarctic zone are in danger of disappearing altogether.

5.3 Adjustment measures

A review of the design flow rates in rivers feeding all major Swedish hydropower dams has been under way since 1990 in line with new guidelines produced by the Committee for Design Flood Determination and the regulations published by the hydropower industry itself (RIDAS). Several installations have been modified and further upgrading is planned.

The principal aim is to ensure dam safety under current climate conditions. We do not yet have sufficiently reliable data to incorporate the effects of global warming in this planning.

However, where possible without incurring too much additional expense, safety margins are sometime increased because of the doubts as to design specifications created by climate change.

There are few other examples of specific action being taken to achieve adjustment. Until adjustment has taken place, the best possible systems will be needed during the period ofadjustment to eliminate and monitor risks and react in the event of emergencies.

5.3.1 Necessary research and development

Research and development is needed to produce more quantitative assessments of vulnerability to climate change and to decide what form adjustment measures should take.

Important areas are:

Development of models and climate scenarios to study extremes in relation to changes in mean values.

- We need to know more about how to interpret large-scale calculation results simulated using global models so as to be able to apply them at regional level.
- Improved integration (eg, interlinking) between various models describing meteorology, hydrology, oceanography and ecosystems.
- Longer data series (30 years) to identify situations occurring rarely (low frequency), eg, violent storms or heavy precipitation.
- Better quantitative assessment of sources of error and uncertainty.
- Research to provide data for impact studies in other areas and sectors (agriculture, forestry, ecosystems, social structure, coastal zones etc).

Studies on the basis of climate scenarios of impacts on all sectors sensitive to climate are also important. Some areas of importance are:

- Agriculture and forestry, fisheries, reindeer husbandry.
- Hydrological processes, soil and groundwater conditions and their importance to landslip and erosion.
- Limnic, marine and terrestrial ecosystems, the initial focus being on important processes, indicative and unique species and habitats, also taking account of other factors affecting these ecosystems.
- Sweden is in a unique position to study epidemiology in relation to a climate gradient. These studies can constitute an important link in assessing the impact of future global climate change on human health.

Studies to formulate strategies for adjusting to climate change. Examples of key areas where adjustment will be needed are:

- Basic knowledge of dynamic processes in ecosystems.
- Ways in which account can be taken now of future changes in conditions affecting the construction of infrastructure with a long lifespan (eg, roads, bridges, water supply and sewage systems, dams, power lines). There is some information about the effects of climate on infrastructure. It ought to be possible to use this more consistently when making risk assessments for infrastructure investments.
- Methods of conserving environmental assets (the mountain, forest and agricultural andscape, coastal zones) and biodiversity by creating and safeguarding migration corridors and micro-environments, which will enable ecosystems to withstand climate change better.

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