6. Vulnerability assessment, climate change impacts and adaptation measures

As a result of global warming, temperatures in Sweden will increase by 2–6 degrees Celsius by the end of the century, depending on climate scenario (www.smhi.se). The temperature rise will vary depending on location, with the most significant rise in temperature expected in the northern part of Sweden. The increase will be more substantial in winter than in summer, which will result in milder winters with decreasing snow cover. Average annual temperatures in Sweden already rise approximately twice as fast as the global average. Climate change will also result in changing precipitation patterns, with an expected increase in precipitation by 0–30 % by 2100, varying by location and scenario. The most pronounced increase will be during winter. During summer, rainfall in southern Sweden is expected to decrease, and increasing evaporation may lead to a shortage of drinking water in certain areas, especially in southeastern Sweden.

Natural and human systems in Sweden will be affected by climate change in a number of ways. Heavy rainfall and cloudbursts are already causing significant economic damage, and deaths have occurred. The occurrence of extreme weather events is expected to increase. Climate change affects human health in various ways, but the magnitude of impacts on health is difficult to predict and varies with local preconditions and the vulnerability of the population. Climate disruption also has important impacts on agriculture, cultural heritage, forestry, housing, infrastructure, the natural environment and ecosystems, reindeer husbandry and many other aspects of Swedish society.

Efforts are being made to improve adaptive capacity, with several national authorities developing adaptation plans for their areas of responsibility. Adaptation plans are also in place at the regional level, and in many municipalities. Significant progress and increased awareness of the importance of adaptation have been achieved over the last few years.

Adaptation to climate change spans many different sectors. Thus, it is important to consider adaptation measures with multiple and cross-sectoral benefits as well as those involving conflicting targets. Furthermore, adaptation to climate change should follow a gender-responsive, transparent and just approach.

6.1 Expected impacts of climate change

6.1.1 Climate research and climate services

In Sweden, extensive research is carried out on climate change and its current and potential future effects. Information from government authorities is freely available and open to all. Although it is not always easy to use or understand for the uninitiated user, efforts are underway to ensure that citizens and stakeholders receive relevant and useable information to enable further adaptation activities.

Research on climate and climate change is carried out at many universities and institutes around Sweden. One of the main sites is the Rossby Centre at SMHI, which focuses on improving the understanding of the future climate with regards to meteorological, oceanographic and hydrological aspects. The Centre conducts work both on model development and evaluation of data, as well as modelling applications for process studies and climate change research in support of impact and adaptation studies.

Scenarios and indices on climate change in Sweden are readily available. SMHI's website at http://www.smhi.se/klimat presents climate information through maps, diagrams and downloadable data, free of charge, on both national and regional scales. Information is also available explaining the results, including uncertainties, and how they have been developed. An introduction to climate scenarios is available (in Swedish). The site also contains guidance (in Swedish) that provides support for interpreting and using climate scenarios.

During 2021, SMHI is reviewing the climate services at smhi.se. The new service will present data from meteorological, hydrological and oceanographical modelling. Since these activities are based on different models and their aim is to present data on different parts of the climate system they will not be entirely consistent. The core is, however, data from CORDEX (cordex.org) at ca. 12.5 km resolution and mostly bias adjusted.

Two degrees globally – projected effects on Sweden

The goal of the Paris Agreement is to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial (1881–1910) levels. According to observations, the average global annual temperature 2020 was 1.2 °C above pre-industrial levels. The rate of warming is approximately 0.2 °C per decade. If the current rate remains, this means that 1.5 °C will be reached in about 15 years, and 2 °C in about 40 years. However, estimates of the rate of warming get less certain with time. A high level of future warming is relatively more dependent on future emissions, compared to lower warming levels, which to a greater extent are the result of past emissions. As the magnitude of future emissions gets increasingly uncertain with time, estimates of future warming rates also get less certain with time.

All warming levels show the same pattern of temperature increase, with the greatest warming taking place in the north of Sweden (Figure 6.1). Note that Figure 6.1 shows deviations from the average of 1980–2010, which is already almost a degree warmer that pre-industrial times.

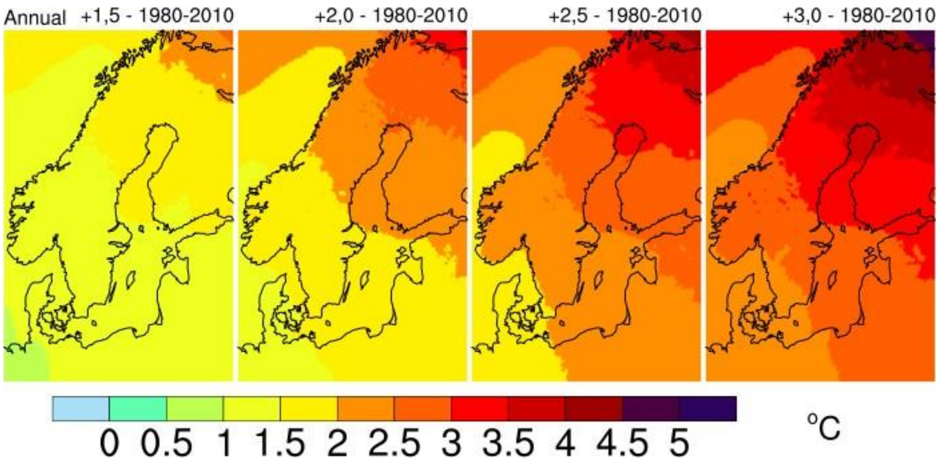

Figure 6.1 Change in average temperature between the reference period (1980–2010) and at 1.5 °C, 2 °C, 2.5 °C and 3 °C global warming compared to pre-industrial time. Note that deviations from the average of 1980–2010 are shown, an average which is already almost a degree warmer that pre-industrial times.

6.1.2 Changes in climate variables

Climate change variables are the basic climatic factors of temperature, precipitation and wind. Changes in these variables will in turn cause climate change impacts.

Temperature

The average global temperature is projected to increase by between 0.5 and 5 degrees Celsius by the year 2100, compared to the reference period 1961–1990. A more pronounced warming than the global is expected in Sweden during the same period.

The regional climate scenarios developed for Sweden, based on global climate scenarios RCP 2.6, RCP 4.5 and RCP 8.5, show that Sweden's annual mean temperature will increase by 2 to 6 degrees Celsius by the period 2071–2100 compared with the reference period 1961–1990, depending on the chosen scenario. The greatest temperature increase is expected to be during the winter, between 2 and 8 degrees by the end of the century. Changes in the summer are estimated to be less than in the winter, with between 1 and 5 degrees Celsius warmer temperatures.

The changes have significant regional differences, with the biggest effect in the north of Sweden. This is mainly due to a decrease in snow coverage, which leads to an enhanced warming since less white snow on the ground, reflecting solar radiation, leads to the ground absorbing more energy. In addition, the thermal conductivity of ground free from snow coverage is greater than if there is an insulating snow cover on the ground.

Precipitation

Precipitation in Sweden is expected to increase by 0–30 % over the next century, depending on scenario and location. Variations in precipitation between different years and different decades are greater than for temperature. This means that it is more difficult to distinguish the trend from variability, and the actual outcome over the coming 5–20 years may not follow the projections. The greatest relative precipitation increase will occur during spring.

During the summer, the precipitation increase in southern Sweden is projected to be small, while changes for the northern part of the country is more significant. It is worth noting that the summer season will extend with climate change.

Snow conditions are affected by increasing temperature. The cold season will be shorter and a larger fraction of the annual precipitation will fall as rain instead of snow. Consequently, the snow season will become shorter and the maximum snow cover less thick, despite increasing winter precipitation.

Wind

Climate scenarios provide no clear answers on how the wind climate might change in the future. Global models show large differences in the changes of circulation across the Northern Atlantic. Small changes in storm tracks can have a large impact on the local wind climate, even though the wind climate in Europe as a whole remains unchanged.

There are many complex factors and circumstances that affect the course, strength and frequency of storms. A warmer ocean surface and more water vapour in the atmosphere etc. contribute to the development of storms. At the same time this warming leads to reduced differences between warm and cold air masses, which play an important role in the development of intense storms. This may in turn counteract the amplifying effect that warming has on storm development.

Projections over Sweden show very small or no changes in wind. The only exception is wind speed over the parts of the Baltic Sea that will become ice-free in a warmer climate. Here, there is a tendency of a small increase in speed.

Milder winters with increased precipitation are expected to become more common in a future climate, and gradually the conditions for ground frost will change. As a result, the risk of storm damage, due to falling trees, can increase regardless of changes in the wind climate. The extent of damage also depends on other factors that are more related to human behaviour and our vulnerability to disruptions in infrastructure, not least regarding electricity dependence.

6.1.3 Climate change impacts

Climate change impacts are described by IPCC as impacts on physical, biological and socioeconomic systems (IPCC, WGII, 2013). Examples of impacts on physical systems include shrinkage of glaciers, decrease in snow cover, longer growing season and more intense rainfall. Impacts on biological systems include species migration and earlier phenology (for example, earlier flowering in plant species). Signals of climate change impacts may be clearer in physical systems than in biological systems, which can also be affected by complex changes that have no relation to climate change, such as land-use change, eutrophication and acidification.

The impacts of climate change are even more difficult to detect in socioeconomic systems, because such systems are not only strongly affected by other changes but also by adaptation processes. In many cases, climate change impacts in socioeconomic systems are in fact adaptation, for example when farmers sow crops earlier in response to warmer spring temperatures.

Impacts on socioeconomic systems are presented with the risks and vulnerabilities in section

6.1.4 Physical systems

Wildfire and drought

Compared to many other countries, Sweden has mostly been spared from major disasters caused by extreme drought. During dry years, however, water shortages pose serious challenges both locally and regionally. Mainly the eastern parts of southern and central Sweden are affected. The extremely hot and dry summer of 2018 resulted in water shortages, damaged grazing and lack of fodder for grazing animals, reduced water levels in certain lakes, and very low groundwater levels in smaller aquifers at the end of summer.

Climate scenarios indicate a decrease in water availability in large parts of southern Sweden. This is mainly due to an increased water consumption of plants in a warmer climate with longer growing seasons. The greatest changes in the occurrence of drought are expected in southern Sweden and in areas around lakes Vänern and Vättern, with an increase of over 60 days of drought every year by the end of the century.

Drought can cause water scarcity and hamper vegetation growth. In southern Sweden, water demand is often greatest when resources are at their lowest. High temperatures and a longer growing season will increase evaporation from the ground and from growing plants and will exacerbate the consequences. Drought causes low water flow in waterways and low water levels in lakes, leading to water shortages and competition between different types of water use such as for water supply, irrigation, sewerage or industrial processes.

Drought increases the risk of wildfires. Every year, on average 3,000–4,000 wildfires occur in Sweden. The extent of forest fires varies from year to year, but often more than 2,000 hectares of land are affected. The financial impacts are large in terms of emergency response and damage to forests and buildings. Almost half of all forest fires are caused by human behaviour. The summers of 2014 and 2018 were characterized by unusually large and fierce forest fires in Sweden. In the biggest single wildfire for at least 60 years, almost 14,000 hectares burned in one location in central Sweden in 2014. During the exceptionally hot and dry summer of 2018, many wildfires raged, together consuming more than 25,000 hectares of forest in mid-north Sweden.

It is not just drought and wind conditions, and the composition of the forest, that determine the size of a wildfire, but also how quickly the fire is discovered and the availability of firefighting resources. Consequently, large forest areas in the sparsely populated parts of the north, and along the coast in northern Sweden as well as inland, often suffer from large fires.

Humidity

Humidity is the proportion of water vapour in the atmosphere and occurs when water in oceans and lakes, for example, warms up and evaporates. Humidity has a major impact on weather and climate. Water vapour is the most abundant of all greenhouse gases and has the greatest effect on Earth's warming. As the climate warms, evaporation will increase so that the atmosphere becomes more humid, which amplifies the initial warming.

Low humidity can cause materials to dry out and high humidity can lead to mould or corrosion. If electronic devices are exposed to dry air, this can cause static electricity, while high humidity can lead to condensation with flashover as a result. Foodstuffs can dry out or turn mouldy if stored in too dry or wet conditions. Humidity also significantly affects the formation of ice, for instance on roads, aircraft, wind turbines and masts.

Relative humidity is the amount of water vapour in the air relative to the maximum amount at the same temperature. When relative humidity is high and wind is weak, the air might feel sticky and muggy. During these conditions, sweat cannot evaporate and in combination with high temperatures this can lead to heatstroke.

Growing season

The length of the growing season (the number of days when the average daily temperature for a single period is over 5 degrees Celsius) has already increased in Sweden. The greatest increase is seen in the north, where the growing season has increased by around two weeks since 1980 (www.smhi.se). By the end of the century, the vegetation period is expected to increase by one to two months throughout Sweden, compared to the period 1971-2000.

Changes in the timings of the growing season can cause problems for plants and animals. For example, a plant that flowers too early, before pollinators are active, will not be pollinated.

An increase in temperature will cause temperature zones to move north. Each degree of increase in average temperature corresponds to a south-north distance of about 150 kilometres in Sweden. This impacts ecosystems and plants endemic to a specific temperature zone that is shifting northwards. For example, bare mountainous areas in Sweden are in decline as the tree line progresses northward when the temperature increases.

Heatwaves

While definitions vary, a heatwave normally describes a prolonged period of warm conditions for a specific area. SMHI defines it as "a continuous period when the highest temperature of the day is at least 25 °C for at least five days in a row".

Heatwaves are quite rare in Sweden compared with southern Europe. However, the optimal temperature varies between different countries and since Sweden's population is used to a cooler climate a temperature increase will affect health. Recent research has shown that warm periods lead to both increased mortality and morbidity in Sweden.

For cities, the urban heat island effect is another important aspect. How people live and whether they have access to cooler areas such as lush parks, forests, waterways, cool historical buildings such as stone churches, and air-conditioned indoor environments, are all important factors for reducing the effects of heatwaves. Social isolation can lead to increased vulnerability to extreme heat, and socially deprived areas often provide less access to cool spaces.

For Sweden, heatwaves are likely to occur more often in the future. Researchers at the Rossby Centre at SMHI have calculated that periods with extremely hot temperatures that have occurred every 20 years on average may occur every 3 to 5 years at the end of the century. In southern Sweden, temperatures could reach as much as +40 °C every 20 years.

Groundwater levels and groundwater quality

Groundwater levels will be affected by any future change in precipitation and temperature. For the northern and western parts of Sweden, the increase in precipitation could lead to an increase in groundwater levels. However, groundwater levels are expected to decrease in the south-eastern parts of Sweden due to decreasing groundwater recharge as a consequence of decreasing precipitation and increasing evaporation.

The water table fluctuates between seasons and is lower during the summer, in most of Sweden. The length of the period with a reduced water table during summer may be extended because of earlier snow melt, higher temperatures and longer summers. This can cause problems for domestic water supplies, especially in southern Sweden.

Groundwater quality may be affected by an increasing inflow of surface water, by changes in land use and changes in groundwater levels. Coastal aquifers will be affected due to sea level rise, with a higher risk of salt water intrusion in domestic wells. It is not currently certain when and to what extent this will become a problem in Sweden, since land rise still compensates for some sea level rise, except in the south.

Heavy precipitation

Events of heavy precipitation have a major impact on society. Flooded roads, infrastructure, and buildings as well as ruined harvests are some of the negative effects caused by heavy precipitation. In urban areas runoff often occurs from small areas with a high proportion of impervious surfaces, and this process can be rapid. In winter, heavy loads of snow can overload roofs and bridges.

Extreme rainfall over northern Sweden's second largest city, Gävle, and the surrounding region in August 2021 caused significant damage. In only 24 hours, 161 mm of rain fell over the city, equal to more than double the average for the month. Extensive damage to buildings and infrastructure resulted from significant flooding. In some places, the water levels reached 3 m from street level. Police instructed the city's population of 100,000 not to leave their homes during the event. All public transport was cancelled. Fire and rescue services could only respond to a fraction of the flooding events.

Extreme rainfall can also lead to high water flows in rivers and lakes. A large part of the flooding that affects Sweden is caused by the combined effect of several smaller rain events in succession, when already saturated ground is exposed to additional rainfall. Intense and local thunderstorms can also bring very large amounts of rain. This can cause problems in cities where stormwater systems cannot handle large amounts of rainfall or put pressure on dam structures.

Climate scenarios indicate that torrential rain (more than 40 mm rain per day) in Sweden is becoming more common in a warmer climate. In the future, we can expect more frequent cloudbursts and an increase in their intensity. The intensity of heavy rainfall events may increase by 40–80 % until 2100 (www.smhi.se). As always, there are large regional and local differences.

During summer, the intensity of heavy rainfall is generally estimated to increase by 10–15 % in Sweden by the end of the century. The rain intensity of a 10-year rain, which on average will return every ten years is expected to rise by about 10%. In line with this, the expected return period of a 20-year rain will drop to 6–10 years during the summer and 2–4 years during winter. This is based on comparisons between the periods 1961–1990 and 2071–2100 (www.smhi.se).

Snow, ice and zero crossings

Sweden is a large country with great variations in temperature and precipitation. This is especially apparent when looking at snow and ice cover.

Large amounts of snow can cause major problems in traffic and damage to buildings, overhead power lines and trees. The problems tend to get worse when combined with strong winds or if the snow is wet and heavy.

About 85% of Sweden’s exports and imports are transported via commercial shipping. This is affected by ice cover – large parts of Sweden’s waters freeze every year, and every winter approximately 500–2,000 ships require icebreaker assistance to get in and out of Swedish ports. During severe winters, sea ice may also affect other infrastructure such as bridges, passenger ships and coastal communities. Ice condition can hamper crisis management, such as search and rescue and oil spill response. Snow and ice also provide opportunities for recreation such as skiing and ice skating and for tourism.

With climate change, snow cover duration is expected to decrease, and in the southern parts of the country, long-lasting snow cover is expected to disappear completely. This may reduce the extent of spring floods, but increase water flows during the winter.

The ice season and its geographical extent will also be reduced. In all scenarios, the changes are greatest in the south, while the Bothnian Bay and northern Bothnian Sea are least affected. None of the scenarios indicate that sea ice will disappear completely from the Baltic region during the present century, and it is important to remember that variations from year to year will continue to be significant. This means that severe winter conditions may occur in the future, although they might be less frequent. The same patterns can be seen for lakes. Major changes are expected to occur during autumn with later ice formation, and during spring with earlier ice break-up. This can affect wildlife dependent on ice-cover for raising their young.

A day with zero crossing is defined as a day with temperatures both below 0 °C and above 0 °C measured two metres above the ground. Zero crossings are very common in central Sweden, with an average of 100–120 days per year. The least number of zero crossings occurs in southern Sweden, around Lake Vänern and along the coast. Zero crossings can cause damage to roads, buildings, bridges and other stone constructions. They also increase the risk for traffic accidents and impacts reindeer food search.

It is expected that there will be a decrease in the number of zero crossings throughout the country during autumn and spring. In the wintertime the number of days with zero crossings will also decrease in the south, while there will be an increase in central and northern Sweden.

Sea level and water levels in lakes

Many processes affect the sea levels along our coasts and water levels in our lakes. Processes affecting sea levels include wind, air pressure, regional sea level rise and local postglacial rebound. Water levels in lakes are affected mostly by rainfall, snowmelt and regulation of lakes and watercourses.

Global mean sea level (GMSL) is rising at an accelerating rate. During the period 2006–2018 the rate of GMSL rise was almost triple that of the period 1901–1971 and almost double that of 1971–2006. The primary causes of sea level rise are the melting of ice sheets and glaciers, and thermal expansion caused by rising ocean temperatures (IPCC, 2021).

Global mean sea level will continue to rise over the 21st century. According to *IPCC Climate Change 2021: The Physical Science Basis*, the likely GMSL rise by 2100 is between 28–55 cm under a very low emissions scenario (SSP1-1.9) and 63–101 cm under a very high emissions scenario (SSP5-8.5), relative to

1995–2014. Under a very high emissions scenario, a GMSL rise above the likely range, approaching 2 m by 2100, cannot be ruled out due to deep uncertainty in ice sheet processes.

By the middle of the next century (2150), the likely GMSL rise is 37–86 cm under a very low emissions scenario and 98–188 cm under a very high emissions scenario (SSP5-8.5). Again, due to deep uncertainty in ice sheet processes, a GMSL rise approaching 5 m by 2150 cannot be ruled out under a very high emissions scenario (IPCC, 2021).

Global sea levels are committed to rise for centuries to millennia, due to continuing deep ocean warming and melting of ice sheets. Over the coming 2,000 years, studies suggest that GMSL may rise by about 2–3 m for a peak warming of 1.5 °C, by 2–6 m for a peak warming of about 2 °C, and by 19–22 m for a peak global heating of about 5 °C (IPCC, 2021).

How regional mean sea levels in Sweden will change in the future is mainly determined by the sea levels of the world's oceans and ongoing postglacial rebound (Figure 6.2). Land uplift counteracts sea level rise to varying degrees and in Sweden varies from less than 1 mm/year in the southernmost part of the country to around 10 mm/year along parts of the coast in the Gulf of Bothnia. Factors such as land ice melt, ground water changes, steric effects and changes in sea-level pressure and winds also affect changes in mean sea level regionally (Hieronymus and Kalén, 2020).

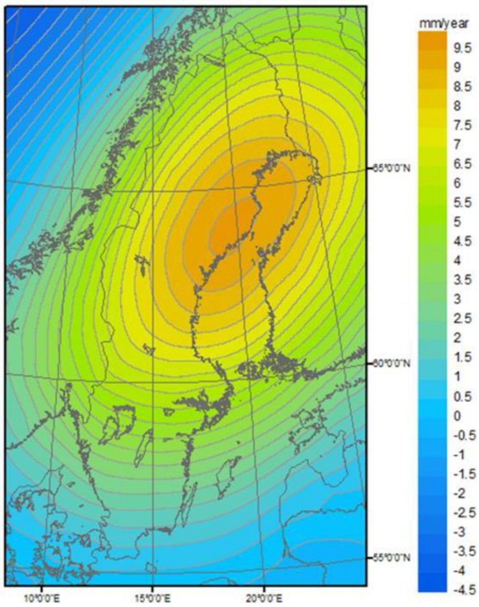

Figure 6.2 Levelled land uplift (mm/year) from the official land uplift model NKG2016LU, released by the Nordic Commission of Geodesy in 2016 and provided by the Swedish Mapping, Cadastral and Land Registration Authority.

SMHI's measurements show that since the late 1800s, sea levels have risen by about 25 cm along the coasts of Sweden, corresponding to an average rate of about 2 mm/year. Consistent with the IPCC's assessment of GMSL rise, SMHI's measurements show accelerating sea level rise in recent years (SMHI, 2021b).

The actual change in mean sea level in most of Sweden has, however, been considerably smaller primarily due to postglacial rebound. In fact, large parts of Sweden are still experiencing decreasing sea levels. The southernmost part of Sweden, where land uplift is close to zero, will be most affected by future sea level rise. However, as sea level rise continues to accelerate, the effect will be evident along other parts of the coast as well.

The water level in lakes is mainly controlled by the amount of inflow and outflow to and from the lakes, how much rain falls directly on a lake and how much water evaporates. Many waterbodies are regulated, and especially in the case of the largest power producing rivers, this has a big effect on water levels. Regulation already affects river flow in ways that are similar to the projected effects of climate change at the end of the century. Regulation typically reduces the spring flood and increases winter flow. It is not possible to give a general answer to how water levels in lakes will change in a future climate. Some lakes may experience higher water levels, while other lakes, mostly in south-eastern Sweden, may have problems with low water levels. Seasonal variations in levels can also change.

High water levels in lakes can lead to flooding with implications for a variety of interests such as housing, agriculture, electricity and water supply. It can also cause increased mobility of pollutants. Low water levels may have implications for water supply, irrigation and ecosystem health, among other things. For lakes Mälaren and Vänern, low water levels can affect shipping.

Flooding

An area covered in water, which normally is not under water, is described as being flooded. The underlying causes vary depending on where the flooding occurs – along the coasts, in rivers, in lakes or in cities. The risk of flooding also depends on other factors such as how waterways are regulated, what preventive measures are adopted and how buildings and infrastructure will change.

Flooding due to extreme water flows may become more common in large parts of southern Sweden and in the north-west of the country. However, local differences are significant. For large parts of Sweden, spring floods are expected to be lower and winter floods will increase. Extreme floods are expected to occur less often in northern Sweden and in the western part of central Sweden. The reason for this is that the most extreme floods in these areas historically have been associated with spring snowmelt. In the rest of the country, extreme floods are expected to become more common.

Storm surges, i.e. rapid short-term increases in sea level that typically occur during situations with strong onshore winds and low pressure, may cause problems with flooding and erosion along the coasts. Flooding of industrial areas may also dislodge pollutants which may move into waterways or into the groundwater.

The mean sea level is the starting point of storm surges. Thus, changes in mean sea level has a direct effect on the severity of storm surge events (Figure 6.3). With rising sea levels and thus a higher starting point, a smaller contribution from the weather is required to reach the same water levels as in today’s storm surge events.

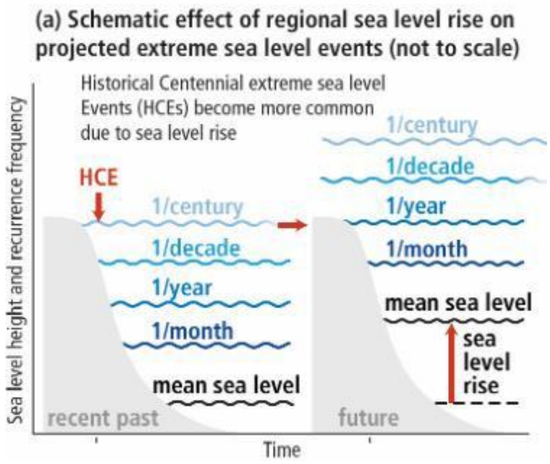

Figure 6.3 Due to projected global mean sea level (GMSL) rise, local sea levels that historically occurred once per century (historical centennial events, HCEs) are projected to become at least annual events at many locations globally during the 21st century. The height of an HCE varies widely, and depending on the level of exposure can already cause severe impacts. Impacts will continue to increase with rising frequency of HCEs. Figure SPM.4 (a) from Summary for Policymakers (IPCC, 2019).

Since the effect of sea level rise is counteracted by land uplift, to varying degrees in different places in Sweden, the likely future change in mean sea level differs by location. Especially in the south of Sweden, where land uplift is small, the water levels experienced during today's storm surges will become more common in the future (Hieronymus and Kalén, 2020).

Hydrological flows

The stream flow patterns in Sweden are expected to change in a future climate. The changes depend mainly on how precipitation will change, but also changes in temperature that affect snow melt, evapotranspiration and the length of the vegetation period.

The annual average stream flow is expected to decrease in the eastern parts of Götaland (southern Sweden) and Svealand (mid-Sweden), while an increase can be seen in large parts of Norrland (northern Sweden). High flows are expected to become less frequent in large parts of northern Sweden as the spring flood is projected to decrease. However, in parts of southern Sweden high flows may occur more regularly. In south-eastern Sweden, low water flows are estimated to become more frequent in summertime due to increasing evaporation and vegetation water demand.

Higher rates of flow can also lead to the inundation of old and new industrial areas, sewage treatment plants, etc. This can result in pollution shocks that may affect human, plant and animal life.

Erosion and landslides

Erosion is the wearing down of the landscape by running water, waves, wind and ice. In Sweden, mainly water erosion is of significance to built-up areas. Coastal erosion is affected primarily by geological conditions, sea level rise, wave climate, wind conditions and currents.

In a changing climate, increasing water flows, more intense precipitation and changing ground conditions may increase the risk of landslides in large parts of Sweden. Increased precipitation and water runoff can cause high flows and erosion along river banks and watercourses. The areas most affected by landslides in Sweden are the western parts of the country and areas in central and northern Sweden. The countryside as well as built-up areas are affected. Decreased soil stability due to increased precipitation and erosion can also cause landslides.

Göta älv, the largest river in Sweden, with its surrounding river basin is very vulnerable to erosion and landslides. In the past, catastrophic events have occurred along the river. As the risk of landslides increases further with an increase in river flow, high discharges to the river from the regulated Lake Vänern are not possible. This in turn increases the risk of flooding around Lake Vänern. The lower reaches of Göta älv are also affected by sea level rise.

In a changing climate, the risk of ravine development might increase in parts of south-western and central Sweden, as well as parts of the north. An increased risk of moraine landslides and mudslides is also expected in central areas.

As a consequence of rising sea levels, coastal erosion will increase along the coast, primarily along sandy coasts in southern Sweden. Frequent sand erosion takes place, for example, along the coast of Skåne, where the coastline has moved 200 m inland over the last 35 years in certain locations.

6.1.5 Biodiversity, ecosystems and climate change

An acceleration of the global mean temperature risks having far-reaching consequences for Sweden’s natural environment and its unique composition of species. A warmer climate with shifting and moving climate and vegetation zones brings significant ecosystem changes. Habitats and populations risk disappearing, moving or shrinking, while others may have new and expanded distribution areas. Climate change also leads to phenological changes affecting the lifecycles of species (seasonal activity, reproduction and migration), and can cause a mis-match between species adapted to each other. Changes in geographical distribution and phenological changes in turn affect interactions between species, food availability, susceptibility to predation or the incidence of pathogens. For example, in temperate aquatic systems, as in Sweden, the timing of the natural spring flowering of algae becomes destabilized or weakened, thus affecting the food base of many other species.

Rapid changes to environmental conditions often lead to favorable conditions for adaptable and short-lived species, while species growing more slowly diminish. In time, this affects the total productivity and stability of entire ecosystem food webs. Extreme weather conditions occurring more frequently and intensively can also lead to sudden disruptions of biodiversity and species distribution. Prolonged heatwaves for instance, could cause damage to terrestrial and aquatic environments, where most species are ectothermic and cannot regulate their temperature. An example of such a sudden disruption is the severe drought that hit Sweden in 2018 which contributed to the extinction of two of Sweden's day butterfly species (Holst et.al. 2020). Biodiversity and ecosystem composition are also threatened by invasive alien species that benefit from more favorable temperature conditions.

Mountainous areas are particularly sensitive to climate change. Warmer temperatures, reduced snow cover and a rising tree line are expected to have extensive negative consequences for Sweden's unique alpine biodiversity and habitats. Parts of Scandinavia's northern mountain range are located in the Arctic, which is warming more than twice as fast as the global average, putting further pressure on its ecosystems.

Elevated water temperatures can considerably affect both freshwater and saltwater species, and species needing colder water may disappear when the temperature rises. Rising temperatures in the Baltic Sea due to climate change leads to a lack of oxygen, and studies from SMHI show that around 30 percent of the ocean floor is suffering from hypoxia. The salinity of the Baltic Sea is also expected to change, due to climatological factors such as increased flows of freshwater due to increased precipitation. These factors, in combination with acidification and eutrophication, have far-reaching effects on marine life.

A changing climate in combination with unsustainable land-use and land-use change leads to extensive loss of biodiversity. Thus, climate disruption compounds other existing environmental impacts and accentuates any lack of biological diversity. Conversely, a rich biodiversity is a key component of a healthy ecosystem, as this increases resilience to climatic disturbances. Thus, protecting and sustainably managing biodiversity, as well as safeguarding intact and functioning ecosystems, becomes an important part of strengthening resilience to a changing climate. Resilient ecosystems are a key factor both for sustainable climate change adaptation and mitigation.

6.2 Assessment of risk and vulnerability

The first vulnerability assessment of climate change impacts in Sweden was initiated in 2005 and resulted in a report to the Government in 2007. The report assessed Swedish society's vulnerability to global climate change, the regional and local impacts of these changes and the costs of the damage caused by climate change. An updated assessment was made in 2015, and a number of suggested actions from this report are now being carried out. For example, an inquiry into the legislative framework for adaptation, detailing any required amendments and clarifying roles and responsibilities was reported in May 2017.

In January 2019, a Government regulation on the work of Swedish authorities on adaptation to climate change entered into force. The regulation establishes that 32 national authorities and all 21 County Administrative Boards, within their areas of responsibility and within their missions, shall initiate, support and monitor adaptation to climate change. The regulation also establishes that these authorities shall implement vulnerability assessments, a task that most of the authorities have completed.

In addition, the Swedish National Expert Council for Climate Adaptation should complete a report every five years, containing an analysis of the effects of climate change on society. The first report was delivered to the Government in February 2022 (www.klimatanpassningsradet.se).

6.2.1 Assessment of impact, risk and vulnerability for socio-economic sectors

Unless otherwise indicated, the information in this section originates from www.klimatanpassning.se, and has been provided by the national authorities responsible for each area.

Spatial planning

Sustainable spatial planning needs to ensure that all future exploitation takes climate change into consideration, thus reducing risks and costs for future generations, and thereby ensuring good and healthy living environments for all. In a rapidly changing climate, spatial planning provides key opportunities for long-term, preventive and resilient climate change adaptation. In order for spatial planning to be effective and long-lasting, it is important to take into consideration the long-term effects of a changing climate on the buildings or infrastructure planned. The climate effects that call for a more sustainable and flexible spatial planning that takes negative effects such as landslides, erosion and flooding, heatwaves, and water shortages into account. Robust spatial planning may prevent the occurrence or reduce the consequences of such events.

In Sweden, landslides, mudslides and erosion, flooding, high temperatures and water shortage are among the priority areas for adaptation, as identified in the National Adaptation Strategy from 2018. Considerable work has been carried out to further analyse and define the risks that these climate effects can bring. For example, an investigation carried out in 2021 identifies 10 geographical areas at risk of landslides, mudslides, erosion and flooding connected to climate change (SGI & MSB, 2021). The investigation also proposes action that needs to be taken to improve conditions for adaptation work that can reduce the risks.

In general, waterfront housing, buildings and infrastructure are often already exposed to the risk of flooding, and are especially vulnerable to the effects of climate change. Rising sea levels will result in an increased risk of flooding in coastal areas. Buildings close to lakes and waterways may be exposed to an increased risk of flooding and landslides as precipitation becomes more intense and frequent in the future. Adaptation measures include soft and hard coastal defences and planned retreat.

Buildings are also affected more directly by a changing climate, through changing snow and wind loads. A warmer and damper climate increases the risk of problems caused by humidity and mould. While the demand for heating decreases in the future, the need for cooling increases, as a consequence of increasing temperatures, and longer and more intense heatwaves. Spatial planning may reduce the effect of heatwaves through the integration of parks, trees and nature-based solutions into planning.

Cultural heritage represents irreplaceable values that need to be considered in spatial planning. Many built-up environments and old cities of great cultural value are located in coastal areas, vulnerable to rising sea levels and extreme weather, and will require adaptation measures.

Health effects

Climate change impacts human health directly and indirectly. A risk vulnerability analysis published by the Public Health Agency in 2021 (Folkhälsomyndigheten, 2021) concludes that the greatest risks to public health in Sweden in a warmer climate are heat waves and tick-borne diseases, with regards to severity as well as likelihood. The analysis also shows that there is a high probability that climate change will lead to a higher prevalence of pollen allergies and water- and food-borne infections, as well as an increase in negative health effects due to an increase in number and severity of floods and a deterioration in drinking water quality.

A reduction in the number of extremely cold days will have a direct positive health effect in Sweden. On the other hand, more frequent and intense heatwaves have a large negative impact on health with significant increases in mortality being reported. Identified vulnerable groups include people with pre-existing cardiovascular and respiratory diseases and socio-economically vulnerable groups. Young children and elderly people are also at risk, especially those who spend a lot of time indoors, where temperatures may be significantly higher than outdoors, particularly if buildings are not adapted to a warmer climate.

Air pollution can further exacerbate the health risks posed by high temperatures. Especially simultaneous heatwaves and forest fires can be harmful. Preventive measures and information for high-risk groups is important, as is adapting buildings such as retirement homes, hospitals and other care facilities to higher temperatures. In the outdoor environment, green spaces such as parks and forests reduce heat exposure and contribute to many other positive health outcomes, both in terms of prevention and health promotion.

Indirectly, a warmer climate affects pollen-producing species and increases the risk of vector-borne diseases. For example, the high-risk season for Lyme disease and TBE may increase by up to four months by the end of the century. A changing climate may also contribute to the introduction of new disease-carrying organisms, vectors and pathogens. There is a need for increased interdisciplinary and inter-sectoral collaboration on human, animal and ecosystem health, primarily concerning surveillance, particularly of zoonotic diseases.

The risk of water borne infections increases during warm summers when more people swim outdoors. Wounds infected by vibrio bacteria in water represent a new problem that emerged in the Baltic Sea region in the 2000s. These bacteria increase in number with higher water temperatures. Higher water temperatures also increase the risk of toxic algal blooms and the growth of gastro-intestinal bacteria.

Climate change also affects mental health. Climate disruption may impact mental health in a number of ways, including through eco-anxiety, i.e. fear over what may happen in a changing climate, and solastalgia, i.e. the distressing sense of loss when familiar environments are damaged or destroyed.

Drinking water

Climate change already impacts the secure supply of drinking water. Increasing average temperatures, greater volumes of precipitation, altered drainage patterns, and changing evaporation and groundwater formation all create new challenges.

Extreme weather events such as heatwaves, drought, torrential rain, storms, flooding, high water levels in rivers and forest fires, lead to quantitative and qualitative changes to raw water resources. Rising sea levels affect groundwater resources through saltwater intrusion into coastal aquifers. As the sea level rises, lakes close to the coastline used for water provisioning may be flooded by sea water and thus destroyed as supplies of drinking water.

The availability and quality of both groundwater and surface water may be affected by a changing climate. Surface water resources are more exposed than groundwater resources to a range of risk factors and are therefore more vulnerable to increases in temperature, precipitation intensity and pollution.

Even in the current climate, low water flows and water shortages occur in parts of Sweden. In the future, it is expected that low water flow will occur more often in southern Sweden, primarily in the southeast. This may lead to shortages or lack of drinking water.

Changing climate conditions place new demands on planning, water treatment and monitoring. To ensure the quality and security of Sweden's water supply in the future, stronger protection of all water supplies, not least water protection areas where drinking water is sourced, becomes even more important. Actions must be taken to manage increasing microbiological and chemical risks in affected areas. Enhanced water treatment technology may need to be introduced to manage bacteria, viruses and parasites.

Stormwater and wastewater

Water drainage systems will be affected by an increasing intensity of rainfall as well as increased water levels in seas, waterways and lakes. In recent years, several incidents of extreme precipitation and flooding in cities have focused attention on urban water management. It is expected that climate change will bring more rain and more intense rainfall. This adds additional stress to water systems.

Improved and extended implementation of nature-based solutions is important for adaptation. Nature based solutions include parks, forests, gardens and green roofs and can also involve waterways, wetlands and sustainable drainage systems. Additionally, reducing the extent of impervious surfaces, especially in cities, by transforming roads and parking lots into parks and rain gardens have multiple benefits in terms of adapting to extreme weather events, as well as improving human health.

Stormwater management requires collaboration across several sectors in society, since one single stakeholder does not have an overarching responsibility for the issue.

Energy security

Climate change affects energy supply, with regard to production, distribution and usage. It can be assumed that in the future most electricity will still be required during the winter, despite an increased need for cooling during the summer in parts of Sweden.

Large parts of the energy system are directly dependent upon the weather and will most likely be even more dependent on weather conditions in the future, due to an increased use of renewables. Thus, the impacts of a changing climate need to be evaluated in light of a rapidly changing energy system. At the same time, climate change will require changes to the energy system.

Extreme weather events have a major effect on energy supply, as high temperatures, flooding, strong winds and storms can cause operational disruptions both in the production and distribution of energy. Many of the interruptions to the electricity supply that occur today, can be attributed to weather-related problems.

Increasing unpredictability is another consequence of climate change, and a growing concern for the hydropower sector. More unpredictable seasonal changes, e.g. in terms of the magnitude and timing of winter snowfall or mild weather, make decisions on water storage in hydropower reservoirs more challenging. If hydropower reservoirs are filled to their maximum in autumn (as has been the case historically), margins decrease for storing water during mild and rainy winters. However, if reservoirs are not filled to their maximum, to keep capacity for a potentially mild winter, but the winter is cold, the capacity to deliver electricity from hydropower decreases.

Climate change will result in certain events taking place with greater frequency and severity than they currently are. Although climate change is not expected to make storms worse in Sweden, storms are (and will be) a significant cause for electrical outages also in the future, due to trees falling across power lines.

Electricity and biofuels are important to the industrial, housing and service sectors. While outages in the electricity supply have direct consequences, disruptions to the supply of biofuels take longer before they affect the user. In a changing climate, biofuel supply can be reduced due to e.g. forest fires and damage to forests from pests and pathogens.

As a result of global heating, an increased need for cooling is expected in summer. However, electricity usage will remain greatest during the winter, as a result of the considerable consumption of electricity for heating. There may be a reduction in the need for heating in the context of a milder winter climate in the future.

The effects on Sweden's energy system will vary throughout the country. The need for cooling is expected to be greatest in the south, where it is likely that the most severe heatwaves will occur.

Dam safety

Hydropower is the most important asset in Sweden's energy system as is manifested by a large number of dams and reservoirs in rivers throughout Sweden. Although an important source of renewable energy, hydropower also harms or destroys river ecosystems and biodiversity along affected rivers. Dealing with this conflict, in a wider context of global heating and biodiversity loss, is an important issue.

An increase in run-off and extreme floods are the dominant concerns for dam safety in terms of climate change. If the inflow exceeds the discharge capacity of a dam facility, the reservoir water level will rise, potentially overtop the dam crest and cause a catastrophic dam failure. For about 400 dam facilities, a failure – with uncontrolled release of the impounded water – would cause significant consequences in the river valley downstream, such as flooding of communities and loss of human lives, serious damage to critical infrastructure and services vital to society and the environment, and/or major economic damage.

Other risks linked to a changing climate and climate-related extremes, e.g. torrential rain, temperature changes, snow and ground frost, wildfires and storms, also affect dam safety to a certain extent, but not to the same extent as extreme floods. In addition to changes in flood magnitude, shifts in flood season could put stress on the operation of complex hydropower schemes and reservoir management.

The potential impact of climate change, the large number of dams in Sweden, their long service-life and the considerable timescale for implementation of adaptation measures, call for a systematic approach and multi-decadal perspective. Adaptation of dams include both structural and non-structural measures. Enhanced discharge capacity is an example of a local structural measure, typically guided by reassessment of design criteria using climate change scenarios. Revision of reservoir operation strategies is a non-structural measure with regional potential in intensively developed river systems.

During 2021–2023 a committee overseen by the responsible authority and state-owned enterprise, Svenska kraftnät, will compile an updated knowledge base of climatological factors and trends of importance for dam safety applications. The committee will map the vulnerability to climate change of high consequence dams in Sweden and outline a climate change adaptation strategy.

Agriculture

Agriculture needs to adapt both to the climate change already noticeable today and to future changes to the climate. Sweden will experience an increase in average temperature, a longer growing season, increased but more unevenly distributed precipitation and more extreme weather events.

Harvests may be negatively impacted as a result of either increased or reduced precipitation. There will be increased risks of drought and flooding, reduced water accessibility, an increased spread of disease and invasive species, changes in species distribution and increased heat stress. Climate change may also lead to more disruptions to trade and infrastructure in the event of extreme weather situations. Increased domestic production of food can reduce the vulnerability to global disruptions to food production, trade and infrastructure.

In the short and medium term, Swedish agriculture may benefit from larger harvests of certain crops and the cultivation of new crops. However, a changing climate represents greater risks. In order to reach a sustainable production of food, agriculture needs to adapt to meet the conditions of a changing climate.

Changes to water management, such as increased irrigation, improved drainage and ecosystem-based management of watersheds are important adaptation measures. Although only about 3% of all water abstraction is used for irrigation, most irrigation is concentrated to the southern province of Skåne. Water for irrigation is needed when water is scarce in streams and rivers, increasing the stress on ecosystems. The need for irrigation is rapidly increasing as the vegetation period gets longer in a warming climate and as the occurrence of droughts and heatwaves increases.

Cultivating a greater diversity of crops and plant varieties, extending the use of integrated pest management practices, and introducing agroforestry are some examples of other adaptive measures already introduced on certain farms. A greater diversity of cultivated crops and a diversification of cultivation methods can spread risks.

Animal husbandry

Climate change increases the risk of outbreaks of infectious animal diseases, mainly due to ecosystem changes and an increased presence of ticks and insect vectors. Many vector-borne diseases are zoonotic, and may spread between animals and humans. However, it is difficult to say to what extent this will happen. It is also difficult to distinguish the impact of climate change on infectious diseases from the influence of other anthropogenic factors.

It is important that Sweden continues to undertake current measures and further develops surveillance and handling of new or emerging animal infectious diseases. Furthermore, established cooperation between concerned government agencies needs to continue.

In a warmer climate, animal husbandry may benefit from an extended grazing season as well as from possibilities for new feed crops. However, drought may cause water scarcity and reduced harvests of feed crops. Farm animals housed indoors may suffer from heat stress, increasing the risks of mortality and disease. Stables in Sweden are in general built to protect animals from wind and low temperatures, not from heat. The risk of heat stress can be reduced by outdoor grazing with access to shade (tree cover), and night time grazing instead of day time grazing, as well as improved indoor ventilation.

Reindeer husbandry

Reindeer herding depends upon well-functioning ecosystems, which makes it vulnerable to climate change. Sudden weather changes, shifting seasons, changes in vegetation and increased unpredictability are among the effects of climate change, posing major challenges to the reindeer herding sector – both now and in the future.

Climate change will result in increased uncertainty, poorer winter grazing, a lack of cooling patches of snow in summer, and uncertainty with regard to ice conditions when moving reindeer herds. Increasing occurrence of zero passages creates difficulties for grazing, resulting in reindeer herding requiring more substantial supplementary resources[63]. A changing climate also has a social and economic impact on Sámi communities. Members of Sámi districts have an exclusive right to reindeer herding in Sweden. In

[63] https://www.amap.no/documents/download/2981/inline

addition, a reduction in reindeer grazing affects biological diversity in the mountain areas negatively, as previously bare mountain regions become covered in bush vegetation[64].

The combined impact of climate change and increased exploitation in northern Sweden makes adaptation measures for reindeer herding more difficult. Reindeer herding can adapt to climate change by reducing vulnerabilities, increasing resilience, improving flexibility and by gaining access to pastures and influence over competing land use such as mining, energy generation and industrial forestry. Climate adaptation for this sector needs a holistic approach, since reindeer herding depends on a cohesive landscape and a functioning ecosystem. Protection of old-growth forests is beneficial to reindeer.

Forestry

Climate change has a direct impact on forests and forestry. In a warmer climate, the growing season is extended, and forest growth will increase. However, the potential for damage to forests will also increase. Milder winters improve the survival of deer, leading to increased grazing of pine and broadleaf vegetation. Conditions will improve for certain insects, pests and pathogenic fungi, facilitating their spread. Invasive species, including potentially invasive tree species, such as *Pinus contorta*, may spread further in a warmer climate.

Climate change demands adaptation of forestry practices. Possible adaptation measures include an increased diversity of tree species used in forestry, an increase in the use of deciduous trees, as well as selective forestry practices and enhanced protection of ecosystems. Also, changing climate conditions are addressed in Swedish plant breeding programmes.

In a changing climate, the risk of forest fires will increase, especially in southern Sweden. When the snow-free and summer seasons lengthen, the fire season and periods with a high risk of wildfire are extended. Deciduous trees and wetlands reduce the impact of forest fires. Thus, restoring deciduous woodland and wetlands may mitigate an increased risk of forest fires.

---

64 https://pub.epsilon.slu.se/15019/8/tunon_h_etal_180122.pdf

As the growing season is extended, more harvesting may occur during this season, increasing the risk of root rot. We may see more storm damage in the future as water levels in the ground become higher during winter and ground frost is absent. Especially the edges of clear-cuts are vulnerable to storm damage. High water levels also lead to an increase in soil erosion if heavy machinery is used in forestry operations, according to current practices. Afforestation during dry years will become more difficult, especially in clear-cut forests.

Improved respect for the forest environment and alternative forestry methods, especially in humid environments and along creeks, will be needed when forestry practices take place on non-frozen woodland. Extending no-cut buffer zones along creeks and rivers constitute one adaptation measure with multiple benefits, both in terms of climate change and biodiversity. Continuous cover and diversified forestry mitigate several impacts of climate change, providing a greater resilience to pest and storm damage, drought, and erosion.

Insurance and financial markets

Climate disruption will present new conditions for the insurance industry and financial markets. An acceleration of climate-related risks, e.g. in the form of more frequent and/or more severe extreme weather conditions, will result in increasing damage costs and hence in higher insurance costs. Indirect costs and risk might also arise due to degrading ecosystems, increasing health-related complications and lower increase in productivity.

The Swedish insurance sector is one of the financial sectors most clearly affected by climate risks due to damage costs from flooding, storms, and drought. The insurance sector is already showing a statistically significant trend towards an increase in number of incidents due to extreme-weather events. Although a great proportion of this trend derives from increasing value of insured assets, climate change related damages are becoming more frequent.

In Sweden, almost all property owners and tenants have some form of insurance protection against natural disasters and damage. This is relatively unique in comparison to many other European countries where it is no longer possible to sign a private insurance with relevance to climate-related risks. However, insurance covers citizens and businesses against unpredictable events. If an event is no longer unpredictable, it no longer qualifies for insurance cover. This may apply to repeated flooding of a basement, for example. Home insurance in Sweden typically includes cover for flooding, but this practice may become difficult to maintain with repeated incidents and increasing costs.

When the risk of damage is deemed too high, it may become impossible to insure property. One national insurance company in Sweden has already stated that they no longer will offer insurance for new development in areas that the count administrative boards has considered unsuitable due to the risk of climate effects.

Furthermore, as stated in Sweden's national strategy on climate change adaptation, the responsibility for safeguarding property is firstly the property-owner (individuals and businesses alike, as well as local and national authorities). This creates a will to avoid new development in high-risk areas and to undertake adaptation measures. Preventive action decreases the risk of flooding. Although no insurance mechanisms currently support preventive action, property owners can, for example, separate wastewater from stormwater and avoid paving surfaces. To support home owners, scientists and insurance companies have developed the web-based tool Vis-adapt (http://visadapt.itn.liu.se/). This tool provides information about the effects of a changing climate and advice on how to avoid damage to buildings.

Especially in major cities, damage may go far beyond individual home owners, as e.g. cloudbursts and flooding can impair important societal functions, including critical infrastructure or health care facilities, leading to escalating damage costs for society.

Climate change will affect financial markets and investments. Key considerations in financial markets include the calculation of risk, achievement of profit through growth and proliferation of financial assets themselves, and avoidance of loss. Balancing different types of risk can be very difficult, and climate change has long been absent in different types of risk analyses. The extension of financial capital to new areas of economic and social life may increase the vulnerability of financial markets to climate disruption, and in turn increase the vulnerability of social and economic life at large.

New government rules, regulations and taxes, the revaluation of fossil energy reserves (linked to the carbon bubble) and extreme weather events are factors that affect financial markets. Thus, climate change, as well as society's efforts to mitigate and adapt to climate change, may have an important influence on financial markets. Especially when political will is present, steps towards a transformation of the financial system are facilitated. The increasingly distant relationship between financial capital and the natural world, society and ecosystems has delayed the response of financial markets to climate change. Making resilience and sustainability fundamental conditions for sound investments would pave the way for a more long-term balance between socioecological considerations, climate risks and investments.

Railways and roads

Transport on railways and roads is likely to increase in the future, which places demands on a robust infrastructure. At the same time, climate change increases the risk of cloudbursts, flooding and landslides, affecting roads and railways. Increasing climate risks may lead to an increase in accidents. Changes in groundwater levels may affect drainage and buoyancy. Low bridges may need to be rebuilt at higher levels. Identifying areas at risk and taking measures can address these problems.

Warmer winters will decrease the need for salting roads, and probably for clearing them of snow. There may be more zero crossings in the northern and central parts of the country, leading to increased risks of difficult driving conditions and damage to roads and other infrastructure. Long periods of warm weather affect railways negatively. Railway lines and various other components can expand in the heat, which may cause traffic disruptions.

The Swedish Transport Administration works to increase the robustness of the transport system by decreasing the risk of damage caused by landslides, erosion and flooding. Trees growing close to railway tracks are removed, and risk inventories are carried out across the country.

Electronic communication

Society is dependent on well-functioning and safe electronic communication, which in turn depends on a continuous supply of electricity. Even short power cuts can have serious consequences for users.

The increased risk of storm damage to forests affects overhead power lines, as well as communication masts. Continuously, work is underway to move power lines underground, making the power supply network less sensitive to weather extremes. However, overhead lines, and the risks connected to them, will remain for years.

During floods, entire areas are likely to lose power, compromising electronic communications. Many large fibre cables are incorporated into bridges and will be damaged if a bridge is flushed away. Work is ongoing to protect electronic communication, for example by increasing the robustness of systems and their resilience to precipitation, wind, lightning strikes, dampness, extreme temperatures, floods, landslides and fire.

Shipping

Shipping in Swedish waters is not affected by climate change to a great degree. Increased water depth resulting from rising sea levels does not bring any negative effects for shipping, but could mean problems in certain ports. Quays in the south of Sweden will need to be adjusted to higher water levels.

Increased water flows could cause problems through an increased risk of erosion and landslides in narrow passages, such as canals. The risk of landslides is high along Göta älv, which constitutes an important shipping route in western Sweden, and shipping there may be affected. An inventory has been carried out of the risks along the river due to a changing climate. Less ice cover and a shorter ice season are positive for shipping.

Aviation

Aviation is not affected by climate change to a great degree. Changes in ground frost and groundwater could affect the buoyancy of airfields, and increased precipitation could put an increased strain on stormwater systems at airports. Heat may affect the surfacing of runways.

The need for de-icing may decrease in the south of Sweden but increase in the north, as winter days become less cold and increasingly damp. Action taken by airports may include continuous maintenance of the stormwater systems and a thicker layer of concrete to counteract the loss of buoyancy.

Cultural heritage

Adapting Sweden’s cultural heritage to climate change involves measures to prevent or mitigate damage caused by a changing climate. Both material values, represented in buildings, ruins, museum collections, objects, archaeological sites and physical landscapes, as well as immaterial values, such as traditional methods of house-building and cultivation of land, need to be considered when adapting to climate change.

The degradation processes for most materials are affected by temperature and humidity. Higher temperatures speed up chemical reactions and changes in materials, and variations in humidity affect the degradation of most materials.

Climate change risks can be both immediate and clearly visible, such as flooding and landslides, but also slow and difficult to identify, such as gradual sea level rise, or mould and overgrowth. Slow effects require systematic monitoring in order to be detected in time. Adaptation activities can also cause damage to cultural heritage sites, for example the construction of erosion protection close to archaeological sites.

Many of the risks to cultural heritage posed by a changing climate can be seen already today, but could intensify, become more common or have greater consequences in the future. Preventive measures such as risk analysis, surveillance and maintenance are essential to prevent and mitigate damage to cultural heritage.

Climate disruption has a particular social and economic impact on Sámi communities and their cultural heritage, which is closely linked to the land and surrounding ecosystems.

Tourism

The COVID-19-pandemic illustrates the substantial impact pandemics can have on tourism. However, both national and international tourism is expected to increase in Sweden, with big cities as a main tourist destination. Coastal areas are important both for tourists and for the recreation of the local population. Here, the most important resources are beaches, lakes and the sea. In the north of Sweden, winter tourism is also very important, as are hunting and fishing tourism. Ecotourism, including wildlife watching, is an emerging branch of tourism in Sweden.

Summer tourism can benefit from a changing climate with higher air temperatures and warmer summers, while conditions for winter tourism becomes more unfavorable. Decreasing snow cover during winter months are already affecting skiing facilities, who are becoming more dependent on producing snow for the winter season. At the same time, the ski resorts have developed towards having activities all year round, with a mixed range of activities. In this way, companies and destinations can become less vulnerable to climate change such as declining snow supply.

Tourism around the Mediterranean may decrease in the future, due to hotter summers. The strong warming expected in the European Alps may lead to decreasing tourism there too. This could bring more tourists to Scandinavia. The tourism industry in Sweden could benefit from a changing climate with warmer summers. However, winters with less snow cover are already negatively affecting ski resorts, which become more dependent on production of artificial snow to prolong a shorter snow season.

Increasing tourism demands management of tourism flows. Tourism puts heavy pressure on ecosystems, water supplies, infrastructure and local communities, and requires limitations, as well as concern for sustainability and resilience in affected communities.

Impact of global change

The effects of a changing climate can have consequences far beyond an affected region. No country is an island in relation to climate change. Cross-border effects result from the interaction of different processes in social and ecological systems and are intimately linked to the global character of climate disruption. Tipping points in the climate system as well as in non-climatological systems may have unforeseen consequences on both global, regional and national level. Transgressing such tipping points, or thresholds, may cause profound and possibly irreversible effects on society. Although difficult to quantify, tipping points involve the largest potential risks of climate change.

It is crucial to include the interaction between climatological and non-climatological factors in an analysis of the effects of climate change on an individual country, or an individual sector, and to keep in mind that these interactions are transnational to varying degrees. For an extensively internationalised country like Sweden, it is important to analyse the consequences for Sweden from changes in the rest of the world. The impacts of climate change on infectious diseases, economic development, trade flows, inequality, security and conflict, geopolitics and migration, as well as the linkages between them, present relevant areas for further study. In both a national and a global context, key considerations also include just adaptation, as well as concern for socio-economic and gender equality in climate change adaptation processes.

Climate-related developments in regions bordering Europe may have profound effects also in Sweden. The heating of the Arctic region, leading to a retreat of sea ice, opens the region to trans-Arctic shipping and exploitation of natural resources. As a result, possibilities for both international competition and cooperation increase. As global heating makes Africa, the Middle East and Central Asia less climatologically liveable regions, migration to Europe may increase further, bringing both substantial challenges and opportunities.

6.3 Adaptation measures

6.3.1 Domestic adaptation policies and strategies

In 2018, the Government presented a National Strategy for Climate Change Adaptation (Govt. Bill 2017/18:163 2018. *National Strategy for Climate Change Adaptation*), aimed at strengthening climate change adaptation work and its coordination in Sweden, including through prioritization of actions and investments. The strategy sets out the aim of adaptation work in Sweden, namely to develop a long-term sustainable and robust society that meets the challenges of climate change by reducing vulnerability and making the most of opportunities. Targets in the Paris Agreement and the Sustainable Development Goals should also be met. The adaptation aims should be taken into account in politics, strategies and planning at the national level, and be integrated into ordinary activities and responsibilities.

The strategy gives the National Board of Housing, Building and Planning the task of coordinating national adaptation work within the field of spatial planning.

Efforts at the national, regional and municipal levels will be needed in order to take climate change adaptation measures into consideration in spatial planning and thus reducing risks and costs for future generations. This work is carried out through close cooperation between national authorities; the National Board of Housing, Building and Planning, together with the Swedish Meteorological and Hydrological Institute (SMHI), the Swedish Geotechnical Institute (SGI), the Swedish Civil Contingencies Agency (MSB), and the County Administrative Boards. Together, these authorities aim to strengthen municipal climate change adaptation work on spatial planning.

The strategy also proposes changes to the Planning and Building Act (2010:900), later adopted by the Swedish Parliament. The altered legislation specifies planning and building regulations requiring municipalities to outline their views on climate-related risks in their comprehensive planning. It also gives local municipalities the power to introduce specific climate adaptation measures, such as requiring a permit for landowners to fell trees or take measures increasing soil imperviousness, if stated in detailed development plans.

The National Strategy for Climate Change Adaptation identifies prioritized adaptation challenges, including: landslides, erosion and flooding that threaten communities, infrastructure and businesses; high temperatures that involve risks for the health and wellbeing of people and animals; water shortages for individuals, agriculture and industry; biological and ecological effects that affect sustainable development; impacts on domestic and international food production and commerce; and increased incidence of pests, diseases and invasive non-native species that affect people, animals and plants.

In particular, the National Strategy highlights the need for identifying specific risk areas in Sweden regarding landslides, flooding and erosion, and to rank them based on likelihood, potential consequences and specific problems. In June 2021, the Swedish Geotechnical Institute (SGI) and the Swedish Civil Contingencies Agency (MSB) delivered a comprehensive analysis of the geographical areas in Sweden most at risk from landslides, erosion and flooding (SGI & MSB, 2021). In a report to the government, ten national risk areas are identified, where complex climate-related risks threaten human lives and health, ecosystems, infrastructure, housing and cultural heritage (see map, Figure 6.4). The analysis concludes that Sweden's capacity for climate change adaptation needs to grow further, both in terms of preventive action, planning and interagency coordination.

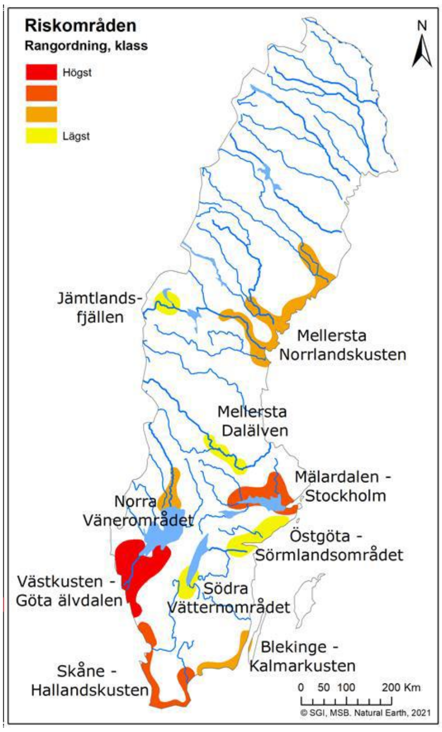

Figure 6.4 The ten geographical areas in Sweden most at risk from landslides, erosion and flooding. Risk areas are ranked from highest risk (red) to lower risk (yellow) (SGI & MSB, 2021).

The National Strategy also identifies ten key principles aimed at guiding climate change adaptation work in Sweden:

- Sustainable development
- Mutual support
- Scientific basis
- The precautionary principle
- Integration of adaptation measures
- Flexibility
- Managing uncertainty
- Managing risk
- Time perspective
- Transparency

The National Strategy will be revised every five years, from 2023 onwards. The Swedish National Expert Council for Climate Adaptation, appointed by the government and established in 2018, is tasked with supporting the government in formulating a revised National Strategy.

The Expert Council for Climate Adaptation evaluates climate change adaptation in Sweden and advices the government on preparing for climate change, by submitting an analysis report every five years. The report is used to support the government in updating the National Strategy for Climate Change Adaptation The first report, submitted to the Government in February 2022, outlines:

- Recommended focus areas for Sweden's work on climate change adaptation
- A prioritization of adaptation measures based on an assessment of risk, costs and benefits
- A cross-sectoral assessment of the societal impacts of climate change
- A follow-up and evaluation of national work related to climate change adaptation.

As the work on adaptation cuts across many different disciplines, it is to a large extent guided by existing legislation, frameworks and targets, both national and international. Examples include the work on Agenda 2030 and on the Swedish Environmental Quality Objectives.

Many Swedish authorities play an important role in adaptation work through their respective sectoral responsibilities and are working on preventive measures, building knowledge, providing guidelines, and improving resilience. For example, in spring 2021, the Swedish Environmental Protection Agency presented Sweden's first national guideline for working with nature-based solutions as a climate adaptation tool.

The regional government offices (County Administrative Boards) are responsible for coordinating regional adaptation and supporting local actors in their adaptation work. The County Administrative Boards report annually to the Government on the actions taken to adapt to climate change.

At the local level, the municipalities are responsible for many operations that are affected when the climate changes, such as physical planning and infrastructure for water, the emergency services, health and social care, schools and childcare. Many municipalities have their own adaptation strategies and plans.

In 2012, SMHI was tasked to form the National Knowledge Centre for Adaptation, to assist municipalities, regions, authorities and other stakeholders in their adaptation efforts. In 2021, the Centre has a budget of SEK 19 million.

6.3.2 Adaptation action plans

The Government Ordinance on the work of Sweden's authorities on adaptation to climate change establishes that national authorities shall implement vulnerability assessments, a task that most of the 53 authorities covered by the ordinance have completed.

Monitoring of the work carried out by the authorities is carried out by SMHI annually. The report on work carried out in 2020 (SMHI, 2020b) shows that many consider risks connected to flooding to be important within their areas of responsibility, and this is also the area where most actions are carried out or planned. However, many authorities still need to carry out additional analytical work to specify risks and opportunities further, in order to identify effective adaptation actions.

An analysis completed in 2020, based on a survey of a majority of Swedish municipalities (SMHI, 2020a) showed that the majority of municipalities have identified the need to take action with regard to climate change adaptation, and around half of the municipalities have developed action plans, at least to some extent. However, few municipalities have evaluated whether measures taken to adapt to a changing climate have made the municipality less vulnerable to climate disruption. Coastal municipalities, larger cities and municipalities close to larger cities, as well as municipalities in the southern part of Sweden, have come further in the climate change adaptation process than rural and northern municipalities.

6.3.3 Implementation

In the 2018 budget proposal, the Government announced a specific initiative for co-financing landslide mitigation measures along the Göta älv river in western Sweden (SEK 215 million in 2021). The risk of landslides along the river is high already in today's climate, but increasing precipitation and increasing drainage will make the risk considerably higher in the future.

Municipalities can also include adaptation measures when applying for other forms of government grants such as the greener cities grant. Through appropriation 1:10 Climate Change Adaptation, preventive and knowledge-enhancing initiatives are funded (SEK 78 million in 2021). Such initiatives have a focus on e.g. landslides, flooding and erosion mapping, directed by the Swedish Geotechnical Institute and the Swedish Civil Contingencies Agency, and on knowledge-enhancing initiatives by SMHI. Climate change adaptation should be integrated into relevant activities and sectors, and spending on increased resilience in projects and sectors is therefore not specified.

In Sweden, the main principle for financing adaptation measures is that the responsibility for preventing and repairing damage due to extreme weather events does not differ from the responsibility for other forms of risk management. This means that the authority or individual who is normally responsible for a sector or property is so also for its adaptation to the effects of climate change.

In built-up areas where the risk of natural disasters is particularly high, municipalities can apply for state funding for preventive actions (through appropriation 2:2 Preventive measures against landslides and other natural accidents). From 2022, the funding available has been increased from SEK 25 million to SEK 520 million per year (www.msb.se). The funding is administrated by the Swedish Civil Contingencies Agency. Contributions can be made with up to 60% of eligible costs or to a maximum of 60% of the value of objects threatened by natural disaster. With this funding, municipalities can implement protection measures against landslides and flooding in practice.

A National Network for Adaptation, consisting of 27 national authorities, all 21 County Administrative Boards and the Swedish Association of Local Authorities and Regions (SKR), provides an arena for knowledge exchange across sectors. The network aims to increase the resilience of society to climate change, and the secretariat for the network is provided by SMHI.

Swedish municipalities, local actors and county administrative boards can also apply for government grants for nature-based solutions for water retention and drought resistance such as river and wetland restoration trough the Local Nature Conservation Initiative (LONA) (total of 108 million SEK 2020). The Swedish Environmental Protection Agency also guides municipalities and County Administrative Boards in their applications for financing trough the EU LIFE-programme for investments in environment and climate action.

The Government also distributes assignments related to various measures to sectoral agencies. Most adaptation issues, however, are multidisciplinary, meaning that work on climate change adaptation is largely performed in cooperation between different actors and sectors at the national, regional and local levels.

Sweden has a well-established and well-functioning framework for disaster risk reduction (DRR), including work in forums for crisis preparedness. The work is coordinated by the Swedish Civil Contingencies Agency (MSB).

Cooperation is promoted on all levels and between sectors and actors working with land use planning, risk management, natural disasters and climate change adaptation, in order to reduce risks and enhance preparedness.

Several coordination forums with relevance for adaptation currently exist in Sweden. Through these forums, sectoral agencies and other stakeholders can share experiences and plan key actions. These forums include:

- Agency network for shore erosion
- Committee on dimensioned flows in hydroelectric dams in a changing climate
- Delegation for landslides
- National network for drinking water
- National network for adaptation
- Regional network for coastal cooperation in Skåne and Halland

Implementation at the local level

Sweden's municipalities are obliged to carry out risk and vulnerability assessments as a basis for coping with extraordinary events and crises. Such analyses also cover events that will be affected by climate change.

Concrete adaptation measures have been initiated in many instances, above all in municipalities hit by extreme weather events. Regarding the nationally prioritized challenges, municipalities have mostly undertaken adaptation measures towards flooding, landslides and erosion, whereas few measures have been undertaken with regards to the effects on domestic and international food production and trade (SMHI, 2020a).

Most municipalities integrate climate change adaptation measures into spatial planning, especially concerning flooding, landslides and erosion. One fourth of municipalities consider heatwaves in their spatial planning, while one third have developed routines, checklists and action plans to counter extreme heat. Examples of physical measures introduced by municipalities include stabilizing and reinforcing measures to counter landslides, measures to manage stormwater through delay and retention of water flows, such as dams, reservoirs and rain gardens, as well as removal of impervious surfaces.

6.3.4 Monitoring and evaluation framework

An assessment report on the Swedish climate change adaptation strategy and the actions taken since 2007 was submitted to the Government in March 2015.

The report highlights the need to develop suitable instruments and indicators to evaluate the implemented adaptation measures. It is proposed that close cooperation should take place with the European Environment Agency to ensure the comparability of any future Swedish evaluation system with the activities of the European Commission.

In 2016, SMHI developed an initial proposal for a system for evaluating and monitoring the adaptation work in Sweden. The system looks at the actions taken as well as their effects.

At the request of the Government, in 2020 SMHI developed a more detailed proposal for a system to monitor and evaluate the national work on adaptation to climate change. The system includes data collection, aimed at answering three questions: 1) Have basic processes been established? 2) Is action being taken, and is it having an effect on vulnerability? and, finally, 3) Have actions proposed in the National Strategy for Climate Change Adaptation been implemented, and is it steering the work in the desired direction? In developing the proposal, experiences from monitoring and evaluation systems in other countries were considered, as were Swedish systems for monitoring and evaluation within other fields. Regard was also given to existing data collection and reporting requirements. A report for the consideration of the Ministry of the Environment was presented in December 2020.

The Government Ordinance on the work of Sweden’s authorities on adaptation to climate change establishes that all 53 national and regional authorities covered by the regulation shall report on their work every year to SMHI. SMHI carries out an analysis of the supplied information, and completes a report to the Government. To date, two such analyses have been carried out, for work undertaken in 2019 (SMHI, 2020b) and in 2020 (SMHI, 2021c).

Sweden reports on its work on adaptation according to Article 12 in the Climate Convention and Article 13 in the Paris Agreement. The first mandatory reporting under Article 19 and Part 1 of Annex VIII of the Governance Regulation and Annex 1 of the Implementing Act to the European Commission was completed in March 2021.

6.3.5 Progress and outcomes of adaptation actions

Sweden is facing climate risks such as sea level rise, flooding, landslides, erosion, storm damage, drinking water contamination, heatwaves, drought, forest fires, spread of diseases and challenges for reindeer herding. Climate change adaptation initiatives in Sweden have advanced significantly in recent years to address such current and future threats.

In Sweden, municipalities play a particularly important role in enabling adaptation to climate change, since they are responsible for the implementation of many climate change adaptation measures in practice.

There is a positive trend regarding municipal climate change adaptation work. However, although 90 percent of municipalities have identified a need to take action with regards to climate change adaptation, the progress of different municipalities varies widely. Few municipalities have evaluated whether measures taken to adapt to a changing climate have made the municipality less vulnerable. Coastal municipalities, larger cities and municipalities close to larger cities, as well as municipalities in the southern part of Sweden have come further in climate change adaptation work than rural and northern municipalities. (SMHI, 2020a)

Case studies on adaptation actions and their outcomes

The Swedish National Knowledge Centre for Climate Change Adaptation gathers case studies on adaptation work in Sweden. The purpose of these case studies is to provide inspiration and to share experiences of different types of adaptation work. Sweden has gathered and described more than 75 case studies on adaptation, at www.klimatanpassning.se, including more than 65 translated into English, at www.klimatanpassning.se/en/cases.

Installing new water treatment filters reduces future economic and health losses

SMHI has analysed a number[65] of adaptation action in order to quantify the costs and benefits. For example, in one case study the analysis shows that installing a new filter in a water treatment facility in Gothenburg, at a cost of approximately €40 million, will deliver benefits worth over €250 million in the form of reduced economic losses due to illness. Importantly, the measure also reduces health risks of around half a million people. The installation of new water filters is partly financed through green bonds.

Agroforestry improves the resilience of agriculture

Agroforestry methods constitute a small but growing niche in Sweden's agricultural sector. Several trials are ongoing, one of them at Hånsta Östgärde farm in Uppland, where fruit and nut trees as well as berry bushes are planted in rows between fields. This agroforestry method increases resilience as risks are spread over a larger number of crops. In hotter and more extreme climate conditions, important benefits of planting rows of bushes and trees between fields include the provision of shade for other crops, temperature regulation, and protection of soil and crops from wind erosion.

Ecosystem based forestry spreads risks in managed forests

Although clear-cutting still dominates forestry in Sweden, alternative forestry methods are being explored on a small scale. Ecosystem-based forestry methods, such as the Lübeck method, are based on the idea that managed forests should mimic natural forests. Such forestry methods could increase the resilience of Sweden's forests to climate change. Mixed forests mimicking natural ecosystems inherently spread risks due to a variation of tree species and age. Such forests are more resistant to pests and invasive species. In a rapidly changing climate, advantages of maintaining a continuous tree cover also include a reduced risk of landslides, erosion and storm damage in exposed locations. Also, less disturbance of the tree canopy improves the ability of forests to manage drought and heavy precipitation events.

Networking at the municipal level reinforces local climate change adaptation

Officials working on climate change adaptation in local municipalities often work alone. This makes it important to identify forms of cooperation between municipalities. Forming local climate change adaptation networks

---

[65] http://www.klimatanpassning.se/atgarda/2.3113/kostnad-och-nytta-for-klimatanpassning-1.105624

facilitates learning from each other and supporting each other in day-to-day adaptation work. One such adaptation network has been established in the Gothenburg region. The thirteen network municipalities meet four times a year, allowing members to share experiences and learn from each other, creating a common knowledge base. An expert group, participating once a year, is associated with the network. This group includes researchers from four universities, a landscape architect, and representatives from the National Board of Housing, Building and Planning and the Swedish Meteorological and Hydrological Institute (SMHI).

Reindeer herding action plans identify vulnerabilities and adaptation measures

To improve the picture of how a warming climate affects reindeer husbandry, and how impacts can be addressed, the Sámi Parliament and the County Administrative Boards in northern Sweden initiated a pilot project, where four Sámi districts carried out climate and vulnerability analyses and developed action plans. The Sámi districts concluded that climate impacts are becoming increasingly evident, affecting reindeer husbandry in many ways. For example, due to landscape fragmentation, many reindeer herding districts lack large contiguous grazing lands to spread their herds on when the pasture freezes. Competitive land use, such as forestry, mining and hydropower, reduces the area of grazing land and makes it more difficult for reindeer to move. Proposed measures include identifying alternative winter grazing land, as forests with hanging lichens, an important feed source for reindeer, have largely disappeared in recent decades due to intensive industrial forestry, including clear-cutting of old growth forests.