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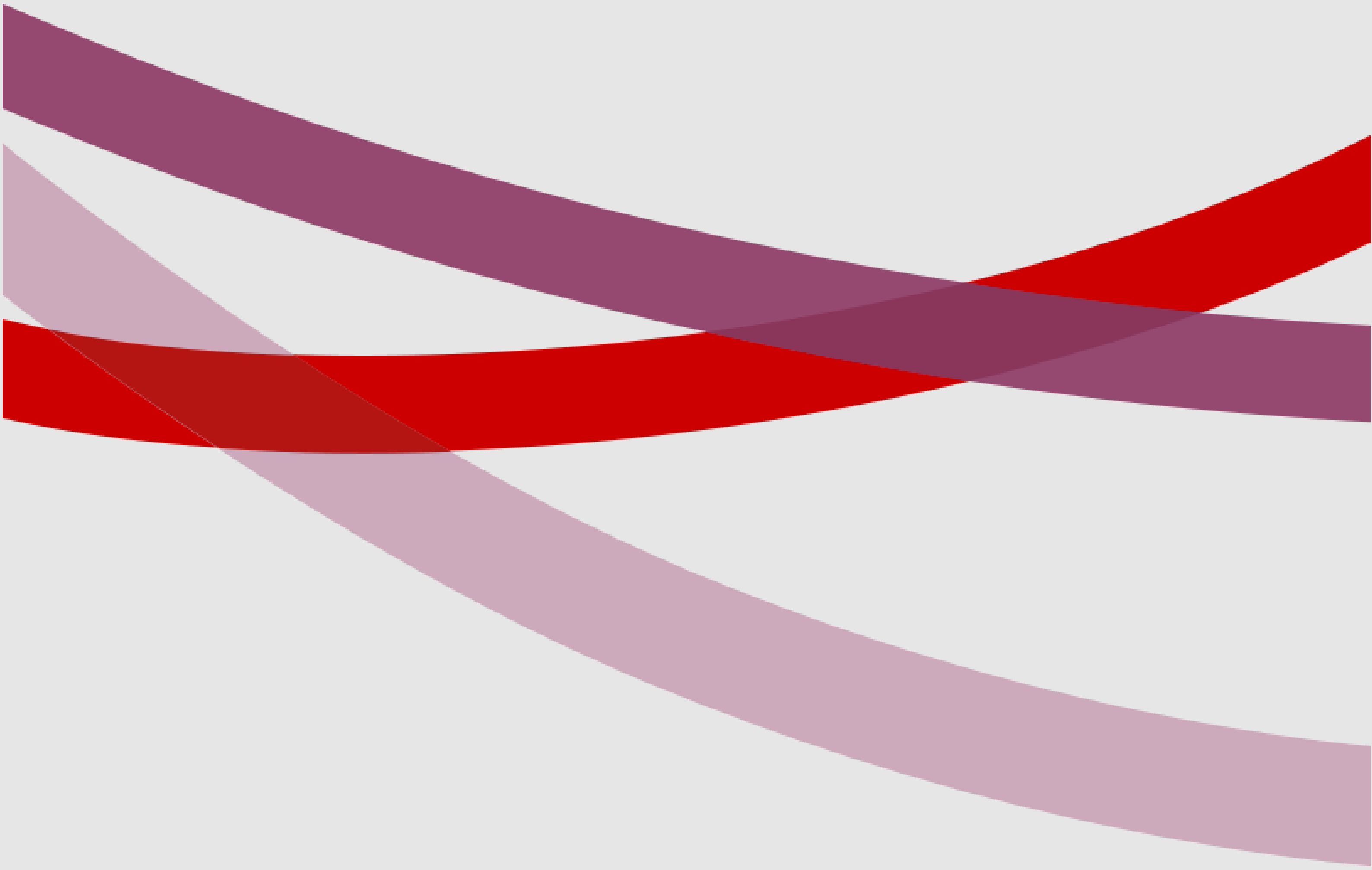

Slow-onset risks from climate change in Sweden in 2050

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Summary (max 400 tecken inklusive blanksteg)

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Cover photo: Foto omslag
Text: Text/Författare
Printing: DanagårdLiTHO

Order Nr.: MSBxxxxx – Month Year
Earlier edition: Datum.
ISBN: ISBN

MSB have initiated and financed this research report (or study). The authors are responsible for the contents of the report, not MSB.

Contents

Introduction

In September 2020, the Department of Crisis Preparedness and Civil Defence of the Swedish Civil Contingencies Agency (MSB) contacted the Department of Physical Geography and the Bolin Centre for Climate Research of Stockholm University. The request was to conduct a literature review regarding the potential risks in Sweden from climate change by 2050, especially those occurring after the adaptation and mitigation strategies are adopted by the Swedish Government to tackle climate change. The study would be developed during four months, from September to December 2020, and would comprise mainly of a literature review.

Uppsala University and Mid Sweden University were also commissioned for the task. After initial internal meetings of the interinstitutional group and MSB, it was agreed that Stockholm University would concentrate on slow-onset risks from climate change. Taking advantage of the Department of Physical Geography's background and the focus of the Research Area (RA3) of the Bolin Centre for Climate Research, our group took a particular focus on hydro climatology and water resources.

Climate change induces various risk factors for society, human health, and the environment through specific impacts. Impacts from climate change can be related to fast-onset conditions related to extreme weather events, such as flooding or wildfires, or to slow-onset conditions that they a more extended period to develop. The Cancun Agreement (COP16) referred to slow-onset risks and impacts as those with more long-term consequences and associated with drivers such as increasing temperatures; desertification, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea-level rise, and salinization, among others.

This report collects the findings on slow onset risks following the approach described in the following section. Section 1 introduces the report, followed by Section 2, where we mention the Approach and Methods adopted. In Section 3, we show the literature review on adaptation and mitigation to climate change in Sweden. In Section 4, we go through the most relevant slow onset risks from climate change in Sweden, including reported present risks and possible risks in the period 2050-2070 and some recommendations to integrate the study of these risks with adaptation and mitigation strategies. Section 5 visualizes Sweden's risk maps under both the RCP4.5 and 8.5 scenarios, and the Conclusion summarizes the main findings.

1 Approach and objective

Many types of potential slow-onset risks can apply to the Swedish case. Sweden's location in a Northern latitude, where some of the most pronounced changes in term of temperature and precipitation increase will occur, in combination with the long latitudinal gradient of the country, the wide range of altitudes, coverage of three crucial biomes (temperate, boreal, tundra) and coasts on two different Seas imply a large number of characteristics, potential impacts, and risks from climate change.

An initial screening of available literature on the occurrence of slow-onset risks in Sweden, available across authorities, institutions, and scientific disciplines obliged us to start with a specific focus. Our reasoning for the development of this report is that in order *to understand potential changes in the distribution and magnitude of slow-onset risks after mitigation and adaptation to climate change in Sweden in 2050, it is necessary to understand the potential risks without such adaptation and mitigation measures.* Although there is a wide span of information and studies dealing with most slow-onset risks, either carried out by Swedish Authorities or scientists, they are not collected in a specific site or location, enabling an adequate screening. Climate change risks can also cover many disciplines, aspects of society, ecology, and meteorology. Some may be more relevant for the daily activities of Swedish society, while some may occur unnoticed. It is an overwhelming task to reflect on all occurring risks under such a short period for such task.

To help understand risks in Sweden by 2050, we decided to organize our study upfront by setting focus on specific types of risks that we consider relevant for the Swedish case. The risks mentioned here are related to water resources or water fluxes. Risks can relate directly to water availability, both on the surface and below ground, or indirectly to a specific context where water is relevant. Such is the case of health and environment, as water availability may play an important role. Also, hydro climatological changes are sometimes difficult to separate, as climate change not only imposes changes in energy availability through temperature but also in water availability in the form of pf precipitation.

This study's main objective is to perform a literature review on the potential slow onset risks occurring in Sweden due to climate change by the year 2050. We also aim to map these risks spatially. Fast onset risks such as floods and forest fires are not included in our list of risks. From the start, we noticed that to understand the occurrence and nature of slow onset risks, it was necessary to directly obtain some of the simulations of changes to hydroclimatic conditions in Sweden and be able to combine these simulations with other spatial data. This is why we focused some resources in downloading data from the Coordinated Regional Downscaling Experiment (CORDEX) climate model simulations at a 50-m horizontal resolution over Europe with the Rossby Centre regional atmospheric model (RCA4) (https://esg-dn1.nsc.liu.se/projects/esgf-liu/) of the Swedish and

Meteorological and Hydrological Institute (SMHI) (Strandberg et al. 2015). We combined these data with other spatial data on agriculture, water resources, sea-level rise, and biomes to understand these risks better. We acknowledge that there is plenty of uncertainty regarding the nature, extent, and occurrence of this risk. There is also uncertainty on the magnitude of the importance and relevance of these risks. Our approach may have also limited going deeper into aspects of uncertainty and more detailed on the nature of these risks and limiting the extent of the literature review. We are also aware that we may have missed important information, studies, and reports related to the occurrence of slow-onset risks in Sweden and adaptation to offset these risks. However, we consider that the literature review, in combination with the analysis here done may shed some additional light regarding the occurrence of slow-onset risks in Sweden

2 Data and methods

This section presents the data used to map the projected change in hydroclimatic conditions in Sweden.

2.1 Selection of slow-onset risks

The initial selection of slow-onset risks covered in this report was based on two internal workshops performed at Natgeo and several biweekly meetings held with MSB and the two other participating Universities. The risks are the following, with names representing the most important aspects of each risk:

1. Blue groundwater drought
2. Green water risks for agriculture
3. Pests in agriculture and forestry
4. Groundwater contamination
5. Salt water intrusion
6. Health risks due to rising temperature
7. Risks to terrestrial ecosystems
8. Risks in aquatic and marine ecosystems

2.2 Literature review on slow onset risks

A literature review was made to find the risks mentioned on a national and regional scale by Swedish authorities and counties. The reports on climate adaptation were collected from the Swedish authorities and counties listed on the Climate adaptation portal: https://www.klimatanpassning.se/vem-gor-vad/vad-gor-myndigheterna/myndigheternas-handlingsplaner-for-klimatanpassning-1.157316. Based on the risks identified in the climate assessment reports, we predefined a list of slow-onset risks. Additional information on the risks was obtained from the scientific literature. Scientific literature was searched and obtained from the EBSCO Discovery Service (EDS) database via Stockholm university library.

2.3 Climate projections and proxies to assess risks

We used climate model simulations at a 50-km horizontal resolution over Europe from the Coordinated Regional Downscaling Experiment (CORDEX), which provides downscaled global climate simulations (Giorgi et al., 2009). Among all the available downscaling models, we selected the Rossby Centre regional atmospheric model (RCA4) produced by the Swedish Meteorological and Hydrological Institute (SMHI) because it has been widely tested and validated for the Northern European region (Strandberg et al., 2015). To account for uncertainty in the climate projections, we used an ensemble of simulations from the RCA4 forced by five different global climate models (GCMs): CCCma-CanESM2, CNRM-CERFACS-CNRM-CM5, CSIRO-QCCCE-CSIRO-Mk3-6-0, IPSL-IPSL-CM5A-MR, and MIROC-MIROC5. The simulations were obtained from the data archive of the Earth System Grid data distribution portal (ESG, http://www.earthsystemgrid.org). We focused on variables related to energy and water availability, such as temperature, precipitation, runoff, soil moisture, and evapotranspiration, as extracted directly from the simulations. We analyzed data at the annual and seasonal scales.

Changes in hydroclimatic conditions in this report refer to the difference between the mean values of two periods, 1980-2000 as a reference of current climatic conditions and 2050-2070 for near-future conditions. For the period 1980-2000, we used historical simulations with forcing from the five different GCMs, while for the conditions of the period 2050-2070, we used predictions from the future scenario RCP 4.5 and RCP 8.5 forced by the same five GCMs.

Representative Concentration Pathways (RCP) are scenarios for the time series of emissions contributing to the greenhouse effect and are defined by the radiative forcing in W/m2 in 2100 (SMHI, 2018). RCP 8.5 represents a future with continued high greenhouse gas emissions globally, reliance on fossil fuels, global population growing to 12 billion, and limited climate politics. RCP 4.5 represents a scenario where global greenhouse gas emissions start to decrease from 2040, the global population grows to below 9 billion, and climate politics are strict and effective (SMHI, 2018).

For both twenty-year periods, we calculated the annual average for the following monthly variables, which from our view could represent proxies to assess slow-onset risks from climate change in Sweden. The variables are Daily Maximum Near-Surface Air Temperature (°C), Daily Minimum Near-Surface Air Temperature (°C), Near-Surface Air Temperature (°C), Evaporation (mm), Precipitation (mm), Total Runoff (mm), Total Soil Moisture Content (mm) and Snow Melt (mm). More information on the variables are available at https://is-enes-data.github.io/CORDEX_variables_requirement_table.pdf

For the assessment of specific risks, we estimated annual potential evapotranspiration (PET) as a function of annual mean temperature (T), following the Langbein (1949) model. The PET is simply the evaporation that occurs in open water surfaces and with an unlimited supply of water:

Land cover data were retrieved from Naturvårdsverket (2020c). The raster data was resampled to a 1000-m resolution. The shapefiles for agricultural areas in Sweden by plot were obtained from the Jordbruksverket inventory (2012) and open waters from the Swedish Meteorological and Hydrological Institute (SMHI). Biome data and extent were obtained from the dataset of terrestrial ecosystems by Olson and Dinerstein (2002).

3 Background on mitigation and adaptation in Sweden

3.1 Mitigation

The Swedish climate law (2017:720) states that Sweden aims to lower its greenhouse gas emissions to meet the long-term emission goal of lowering total carbon emissions within its borders to net-zero by 2045. However, all greenhouse gas emissions cannot be eliminated with current knowledge and technology. The emissions that cannot be reduced to zero come from cement production, sewage treatment, biofuel combustion, and diffuse sources in agriculture (SOU 2020:4). In comparison to 1990, a maximum of 15% of the reduction can be attributed to supplementary measures such as absorption of carbon dioxide (CO_2) from forests and other land types, mitigation efforts outside Sweden's borders, and carbon capture and storage (CCS) of biomass. Increasing CO_2-absorption from vegetation is proposed by planting trees on former agricultural land and rewetting forest and former agricultural land that were previously wetlands (SOU 2020:4). In several industries in Sweden, such as the pulp and paper industry, CO_2 emissions are generated from the combustion of organic material, and there is potential for CSS to reduce the emissions in these point sources (SOU 2020:4). On a longer timescale, carbon could be potentially stored in Sweden; however, research is needed to know how suitable locations are. Soon, carbon would have to be transported outside of Swedish borders and stored abroad. Currently, however, there is no government agency responsible for CSS, and there is a lack of legislation and economic incentives for the transport and storage of carbon (SOU 2020:4). There are many other possible types of negative emissions that are discussed, but there is significant uncertainty on the suitability and applicability of these measures. Nevertheless, there is consensus that it is best to invest in several types of supplementary measures for risk diversification (SOU 2020:4).

In the proposition 2019/20:65 the government outlined an action plan for the climate mitigation of Sweden. In the construction sector, the actions include increased recycling of building materials and increased use of wood in the construction of buildings. The industry sector emissions make up about a third of the total emissions from Sweden (Prop. 2019/20:65). The government will make investments in developing new technology, which will be necessary to achieve net-zero emissions. Development of CCS and Carbon Capture and Utilization (CCU) technologies and improved plastic recycling methods are thought to be needed, and there is potential for domestic production of renewable fuels, including jet fuels and biogas (Prop. 2019/20:65). Production of batteries within the country can increase the industry's sustainability and secure access to batteries for electric cars. The supply of minerals from Swedish mines is also expected to be more critical and more sustainable than relying on imports from other countries, as these resources are needed in electrification processes. The government wants to encourage continued investments in renewable energy sources such as solar and wind power and increase energy use efficiency in the future. However, electrification may also put high pressure on the electricity supply system. For this, the Swedish government intends to set up a national strategy for the bio-economy or use renewable biological resources from land and sea to produce materials and energy (Prop. 2019/20:65). Currently, biofuels are mainly sourced from residuals from agriculture and forestry (Black-Samuelsson et al., 2017). However, additional biomass could be produced in fields where there is no longer active agriculture or forestry (Prop. 2019/20:65) or current agricultural fields in the fallow (Jordbruksverket, 2012b). While there is potential to increase the supply of biomass from increased efficiency and cultivation on available land, biomass demand is also expected to increase. Biofuels can replace fossil fuels, and wood can be used instead of other more climate-intensive materials (Naturvårdsverket, 2019a).

3.2 Adaptation

The government has introduced a national strategy for climate adaptation. Agencies must take a risk and sensitivity analysis, set up goals for climate adaptation, and specify plans for measures to reach the goals. Counties are responsible for coordinating and supervising climate adaptation work in municipalities in their areas and other regional agencies' work (SMHI, 2020b). In the work of climate adaptation, the government has decided on some guiding principles. There are also several prioritized challenges for the adaptation work.

The agencies are required to report on their work to SMHI. In 2019, 30 of 32 agencies and 20 of 21 counties had reported on their climate adaptation measures. SMHI published a report on these reports' status and analyzed the content (SMHI, 2020b). They remark that many of the authorities have not yet integrated climate adaptation principles into their regular work. This process needs to continue before specific risks, and associated adaptation measures can be defined. The climate change risks that were found to be relevant to most of the authorities' work were mainly fast onset risks, mainly associated with flooding, erosion, and mass movements. Fast onset risks relate to sudden events such as floods, hurricanes, or wildfires, threatening and infrastructure, and immediate losses, specifically life and livelihoods. Responses to these risks are often addressed through emergency management plans on national and regional levels. The system that agencies and counties report to is still being developed to address the shortcomings discovered in SMHI's report. The goal is to develop a database of adaptation measures, to improve cooperation between authorities further. The responsibility is shared between different actors for several measures, and the implementation should therefore be conciliated. At this stage, some authorities have defined many measures while some have not reported any. The measures described range from very specific to very general, and while some measures are designed to adapt society to the risks of climate change directly, others target earlier steps in the process towards adaptation. This process includes collecting and increasing knowledge of the risks, producing guidelines, integrating a climate perspective in all regular work, implementing contingency plans, and increasing Sami villages' financial resilience.

The agencies who have defined adaptation measures often indicate that the measures can address multiple of the prioritized risks and help achieve goals from Agenda 2030 and the Paris Agreement. There can be a broadly positive effect from many of the measures. SMHI has written a summary detailing what a climate-adapted Sweden would look like based on the adaptation measures reported to them (SMHI, 2020b)*)*. Based on the agencies' and counties' answers, SMHI has identified some areas where there may be conflicting objectives. Care must be taken that a measure taken to adapt to one risk does not negatively impact another objective. For instance, the drainage of surface water from agricultural or urban areas may lead to an increased risk of flooding downstream of the area. The act of draining an area may also impact ecosystems and decrease resistance to drought. Nature-based methods of climate adaptation, for example, in coastal zones, can negatively impact habitats and ecosystems and an increased risk of introducing invasive species (SMHI, 2020b).

On the Swedish Portal For Climate Change Adaptation (2020), there are 20 agency reports available. While the agencies have set long-term goals for climate adaptation, the plans focus mainly on short-term measures to take them towards those goals. Most of the measures are to be executed within a few years. There is a lack of knowledge on adapting to climate change and the most effective measures to do it. Many of the agencies propose measures focusing on gathering information, conducting research, communicating externally and internally, and evaluating and integrating their current processes regarding climate adaptation. More specific measures are likely to be introduced in a later stage. The agencies must gather necessary information and communicate this to the lower levels (e.g., municipalities). Cooperation is also essential in the plans, both on a national level between different authorities and internationally. Other authorities have seemingly reached further in their climate adaptation work and have proposed many measures to adapt to the effects of climate change—the measures defined by each agency relating to each agency's specific responsibilities. Green infrastructure or nature-based protection against flooding and erosion are mentioned in plans by, for example, HaV (2018), SGI (2017), Skogsstyrelsen (2020), and Naturvårdsverket (2019b). Other examples of measures include detection methods for new diseases (Folkhälsomyndigheten, 2017a), setting up protected environmental zones (HaV, 2018; SGU, 2017) or financial support to Sami people to increase income security and to promote a more diverse economy that is more resistant to climate-induced changes (Sametinget, 2017).

Different agencies refer to different future climate scenarios, depending on their responsibilities and perspective. Examples of agencies that use the 'business as usual' scenario RCP 8.5 for their risk assessments are MSB (2020), Elsäkerhetsverket (2018), and Statens Fastighetsverk (2020). Their reasoning follows the precautionary principle that using the scenario RCP 8.5 represents the worst possible scenario. Most other authorities base their analysis on RCP 4.5, while some do not specify if they use any particular scenario.

Adaptation to climate change is often a slow process that relies on several factors to be successful, and changes can be slow. For instance, a national goal is to diversify the tree species in Swedish forests to spread the risk of forest fires.

Felton et al. (2010) calculated that only one percent of the total forest area in Götaland was available for cultivation of other tree species at the time of their study. The process of diversification of tree species is dependent on the actions of the forest owners. Since most forest land in Götaland is privately owned, owners need to be provided with incentives and information to carry out the necessary adaptation measures (Felton et al., 2010).

While awareness of the risks is essential, there may be other obstacles in the way of adaptation. A recent study investigated the opportunities for local cooperation of water resources in Göta Älv (Bendz and Boholm, 2019). The study found that stakeholders were aware of the different risks to water resources, including climate-related risks, and the need to manage those risks. While it is known to be beneficial to cooperate on water management across municipal borders, there are obstacles to such cooperation, partly related to lack of trust between different municipalities.

Swedish farmers are aware of the risks and opportunities associated with climate change, but in general, they do not perceive climate change as an “immediate concern” (Juhola et al., 2017). Farmers take measures to cope with the risks of climate change. These measures are mostly incremental or systematic. For example, measures to avoid soil compaction during wet periods, improved drainage systems, and taking advantage of a longer growing season by choosing different crops and introducing winter crops (Juhola et al., 2017). Since many other factors other than climate change impact farmers’ investments, economic and political policy are valuable for further climate adaptation (Jordbruksverket, 2018b). The experience gained from the 2018 drought can have the positive effect of increased cooperation and preparedness for similar events in the future, according to the Swedish Agricultural Board (2019).

The aim in Sweden is to increase domestic food production while still decreasing the negative climatic impacts. The aim is not feasible without developing improved technologies and methods within Swedish agriculture (Jordbruksverket, 2018a). For Nordic agriculture to become more self-sufficient and sustainable in the future, there is a need to produce more animal feed domestically (Åby et al., 2014). Since different agricultural products have lower or higher emissions, changes in the demand for different products may significantly affect the total emissions from Swedish agriculture (Jordbruksverket, 2012b).

There are several possible ways that an adaptive measure can have an unintended negative impact, either in the exact location of the application or in a neighboring location, often referred to as maladaptation. For example, maize is a crop that is known to benefit from a longer growing season and could be cultivated in Sweden in the future (Neset et al., 2019). However, maize cultivation requires a lot of fertilization, which could worsen problems with pests and weeds. Pesticide use is expected to increase to cope with increased pressure from plant diseases in a wetter and warmer climate, a negative effect on water, soil, and food quality. Irrigation during drought periods can worsen water scarcity problems. Drainage systems to adapt to heavier rains could affect downstream environments, such as nearby farmland or wetlands. The risk of nutrient leaching from agriculture increases, contributing to eutrophication (Neset et al., 2019). It is expected that without the use of drainage systems, agricultural land is unusable (Wesström et al., 2017). Reducing nutrient leaching by not plowing fields implies increasing the need for chemical plant protection against weeds as weeds are not removed by plowing (Eckersten et al., 2008).

4 Slow-onset risks of relevance to Sweden

Chapter 4 will go into the risks mentioned above, describing currently existing risks mentioned in the literature and discussing possible and expected risks in the future period 2050-2070. The future risks are evaluated concerning climate change projections with selected proxies that may deem relevant for assessing the risks.

4.1 Blue groundwater drought

- **Changes in groundwater supply in southern Sweden can affect public and private water supplies as less water is available, especially within minor-scale aquifers.**
- **Drinking water supply from groundwater in southeastern coastal aquifers is at greater risk as aquifer volumes are smaller and prone to low groundwater levels over summer.**
- **Increased seasonal variations of groundwater in northern Sweden**
- **Lower crop yields concerning low groundwater levels over summer and their impacts on irrigation of agricultural land**

4.1.1 Current risks

Since society and ecosystems, for the most part, rely on water stored within the landscape (lakes, rivers, aquifers, soil) rather than from direct precipitation, risk assessments of drought focus primarily on hydrological or soil moisture drought. Water resources such as freshwater in lakes, rivers, and aquifers are defined as blue water, and blue water hydrological drought can then be defined as the conditions when water levels fall below average conditions in these resources (Van Lanen et al., 2012; Van Loon, 2015). For instance, the Geological Survey of Sweden (SGU) defines hydrological drought as the deviation of the recorded groundwater level in the middle of the month from the average groundwater level of that specific month during the period going back to the 1970s. Hydrological droughts can impact sectors such as drinking water supply, irrigation, and energy production (Alcamo et al., 2003; Kundzewicz et al., 2008; Siebert et al., 2010; Prudhomme et al., 2014; Van Loon, 2015; Jägermeyr et al., 2016; Porkka et al., 2016; Wu et al., 2020).

Sweden experienced a severe groundwater decline from normal levels in August 2017, especially in the country's southern and central parts (SGU, 2017). The resulting societal impacts of the drought included irrigation bans, water consumption restrictions, and private wells running dry in southern areas. This decline in groundwater can be linked to the volume and spatial distribution of precipitation and temperature, affecting the subsequent recharge of groundwater levels. For Sweden, climate change scenarios have predicted increasing temperatures, high uncertainties in precipitation during spring and summer (growing season), and an increase in precipitation over winter. The European Environmental Agency states that droughts are expected to increase in frequency, duration, and severity across Europe (EEA, 2020b). Temperatures and days with low soil moisture are also expected to increase, as indicated from climate simulations (RCP 4.5 and RCP 8.5) (SMHI, 2020). SMHI showed that the difference between precipitation and evaporation is projected to increase from 30% to 60% during winter and decrease from 20% to 40% during summer, especially in Southern Sweden (SMHI, 2003).

A study by Steffens et al. (2015) focusing on Scania and Halland's counties showed that annual precipitation could increase by 12 and 25% and temperature by 2 and 3.5°C, respectively. Using different climate models for varying projections, they found that northern parts of Sweden may experience increasing discharge, which is the volume per unit of time running on a hydrological basin's surface. On the contrary, southern Sweden may instead face decreasing discharge, although results present high uncertainty (Arheimer et al., 2013). Specific runoff in some areas of Sweden is expected to decrease between 150 and 200 mm, which corresponds spatially with projected reductions in groundwater levels. Groundwater levels are projected to increase by 10 cm across Sweden (Arheimer et al., 2013).

Seftigen et al. (2013) reconstructed the summer drought for south-eastern Sweden and found that extended dry periods resulted in a negative impact on forest growth and crop production. When combined with high temperatures, the adverse effects increased due to increasing evapotranspiration leading to hydrological drought where soil moisture is reduced, and lake levels decrease due to increased evaporation. A dry summer in 2013 and 2017 led southern Sweden's large areas to experience groundwater levels below normal (SGU, 2017). Drought years have been correlated with historical variations in the frequency of forest fires and burnt areas in Sweden by Ou (2017). Drought conditions are projected to increase in severity in southern Sweden, especially towards the end of the century, inducing in some cases hydrological droughts. Contrary to these former projections, a study by the European Environmental Agency in 2020 (EEA, 2020a) found climate change to increase crop yields in Northern Europe.

A study by Vikberg et al. (2015) examined current average groundwater fluctuations throughout the year for different parts of Sweden. They found a significant difference between southern and northern groundwater levels throughout the year. Northern aquifers start the year with low groundwater levels that decrease even further up to March when there is a sharp increase in recharge by snowmelt. From the end of May, there is a slow, gradual decline in the water level. Groundwater levels in the south increase from January to March, after which they start decreasing. The lowest groundwater levels occur in October and November after consumption during summer. Recharge starts again as the climate becomes wetter in November and groundwater levels rise once again.

In 2015, the total water use in Sweden was estimated at 2,444 million cubic meters (or 2.4 km^3). Approximately 80% of this use was surface blue water. Bluewater refers to the water that is stored in stocks such as lakes, aquifers, and rivers. Groundwater accounted for just over 13% of the total freshwater extraction (SCB, 2017). The industry sector is the largest water user in Sweden, accounting for 61% of all blue freshwater use. Approximately 23% of blue water is used by households, with agricultural water use accounting for just 3% of the total blue water use. Bluewater shortages are often linked to low groundwater levels and occur mainly in southern and central Sweden in areas with large population concentrations along the coasts of Svealand and Götaland. Groundwater supply is also scarce in other areas, especially in Västgötaland and Upplandsslätten, Närke and in Öland and Gotland, under specific seasons. In locations where there is a lack of geological deposits that can store water (mainly sand and gravel), the extraction potential from other deposits is low, leading to local problems for individual use leading to scattered permanent or residential leisure units. Areas with water shortage can be found in large parts of Bohuslän and Dalsland, eastern parts of northern Kalmar and Östergötland, and parts of eastern Svealand, mainly the coastal regions. The water shortage occurs during summer when the need for water for irrigation is the greatest, combined with high water use from a higher population during summer (SCB, 2017).

Currently, the municipal water supply is the dominant source for drinking water, with a quarter from groundwater and three quarters from surface water. Surface water also includes artificial groundwater, which has been infiltrated into a sand or gravel deposit to aid groundwater formation (SGU, 2009). Approximately 8 million people, or 88% of the Swedish population, receive water through the municipalities' public water supply. This supply covers households and public activities such as schools, hospitals, and many companies connected to the municipal water supply. In total, 863 million cubic meters were supplied from municipal waterworks in 2015, of which 23% were supplied by groundwater.

Agricultural blue water consumption consists of two main parts: crop irrigation and drinking water for livestock. Crop irrigation accounts for the most significant part of agricultural water use. Approximately 75 million cubic meters of water were used by agriculture in 2015, with 64% going to irrigation and the remaining 36% by livestock farming (SCB, 2017). It is difficult to determine the exact contribution of surface and groundwater to irrigated agriculture in Sweden. First of all, old surveys show that 85% of agricultural irrigation depends on surface water resources while remaining in private groundwater sources (Johansson and Klingspor, 1977). A survey made by the Swedish Board for Agriculture in 2015 found that 84% of agricultural holdings used surface water sources for irrigation. However, it is not possible to assume that the volume of water is distributed proportionally across farms. Since many farms use several sources, the survey could not estimate the volume abstracted from each source. Current statistics show that water used for irrigation has been steadily declining, which could be the result of more efficient water use within the agricultural sector. There was a 14 million cubic meter reduction in water used for irrigation between 2010 and 2015, from 62 million to 48 million cubic meters, respectively. Irrigation water use has high regional variability, with Skåne accounting for 60% of the total use. Skåne contains approximately 40% of the agricultural land within Sweden and therefore has the most prominent water use in irrigation.

4.1.2 Risks in 2050-2070

In northern Sweden, the most significant changes in groundwater levels are expected to occur during the first half of the year. Increasing groundwater levels are expected due to increase precipitation in winter and snowmelt beginning earlier in the spring. It appears that this increase will be larger than the reductions expected later on by the increased water uptake from plants and evaporation over the summer (Vikberg et al.,. 2015). Increased water uptake and evaporation combined with earlier snowmelt may lead to possible lower groundwater levels over summer, with the restoration of water levels occurring later in the year. Future projections show that earlier snowmelt results in the groundwater level peak occurring and subsequently declining earlier in the year, with a more extended period over summer when groundwater levels are low, with the aquifers' recharge beginning later in the year in future projections. A clear relationship in the north of Sweden can be observed between snowmelt and increasing groundwater levels. Future projections show higher groundwater levels in autumn as more precipitation occurs as rain and recharges the groundwater instead of being stored as snow (Vikberg et al., 2015).

A high water table in northern Sweden may affect water sources with artificial groundwater formation as the unsaturated zone decreases, with less surface water required to restore the reservoir. Surface water supply can also be affected by the more significant proportion of runoff to surface waters in northern parts of the country as the saturated zone increases. Shallow groundwater is generally more acidic than deeper and older groundwater; hence it may contain more metal and generally has a higher content of humic substances (Columbani et al.,. 2016).

Groundwater levels in south-eastern Sweden will decrease (Sundén et al., 2010), especially in autumn and spring due to increased evaporation, both from an extended growing season and higher temperatures.

The most notable change from current levels is projected in the typically highest and lowest groundwater levels in south Sweden due to increased precipitation in the south over winter, recharging the groundwater levels, and increased temperature and evaporation over the summer, decreasing groundwater level. Groundwater levels will decrease in reservoirs that react both slow and fast to seasonal variations. On the east coast, the water levels are expected to be lower than current levels when groundwater starts recharging and decreases further into the autumn. In southeastern Sweden, the most significant groundwater recharge is expected earlier in the year and continued further into autumn at the end of the year. The groundwater levels are projected to be highest at the beginning of the year in January and February (Vikberg et al., 2015). There is a tendency to higher groundwater levels in the south and southeast at the beginning of the year. Although in most southern Sweden, the groundwater level will decrease, on the west coast, summer groundwater levels may increase due to a combination of low pressure and large amounts of precipitation leading to groundwater formation. However, the projections still show a decrease in levels in early spring on the west coast, and the southeast shows the most significant projected variations from current groundwater levels.

Although the groundwater changes in southern Sweden are expected to be smaller than those observed in northern Sweden, the consequences of these changes on groundwater supply will be more significant due to the effect on both public and private water supplies as groundwater abstraction may decrease as groundwater levels decrease as well.

Regarding drinking water supply from groundwater, the most significant challenges will be again in south-eastern Sweden. The public water supply may also face increasing pressure to provide water to larger areas where the water supply will be scarce. The pressure is especially relevant in coastal areas where the reservoir volume is small, and extended summer periods without groundwater formation can be expected to contribute to water scarcity. In general, in areas where groundwater levels decrease, flows to surface water may be reduced, leading to increased problems with the water supply in water infrastructure (Aastrup et al., 2012).

The fluctuation of groundwater levels is expected to decrease in Northern Sweden while increasing in the south and south-eastern Sweden (Nygren et al., 2020). Seasonal variations in groundwater are expected to change mainly in the north of Sweden for fast-reacting reservoirs, affecting private water supplies. Groundwater levels are estimated to be lower in late summer and early autumn, affecting private water sources due to shorter groundwater recharge periods during the summer months.

Climate change and droughts' subsequent effect can significantly impact water availability for energy and irrigation and crop yields, especially relevant to irrigated areas with groundwater. Campana et al. (2018) show that if no irrigation is applied to crops during a drought year, there can be significant losses of up to 50% in the number of crops produced.

The reason for defining a proxy that can be linked to groundwater levels is to map the risk areas resulting from reduced groundwater. Once risk areas are defined, actions can be taken to mitigate and adapt to the risk. In the absence of a product of irrigated agriculture for Sweden, we combine data on irrigated agriculture (Naturvårdsverket, 2020c) with data on potential irrigated areas with groundwater from Siebert et al. (2013) to provide a map showing the agricultural land within Sweden that is irrigated by groundwater (figure 1). The result is a map showing probably more irrigated areas than those that exist. We focus on the south of Sweden, where the majority of irrigated agriculture is located. We decided to use projections of future runoff over the growing season (March to October) as a proxy for groundwater levels, as extracted from the CORDEX datasets. We hypothesize that a decrease in runoff into the future would relate to lower groundwater levels, representing a potential risk for hydrological drought. The soil is less saturated where the groundwater levels are low, leading to infiltration and reduced runoff, making runoff a useful proxy (Berhanu and Hatiye, 2020).

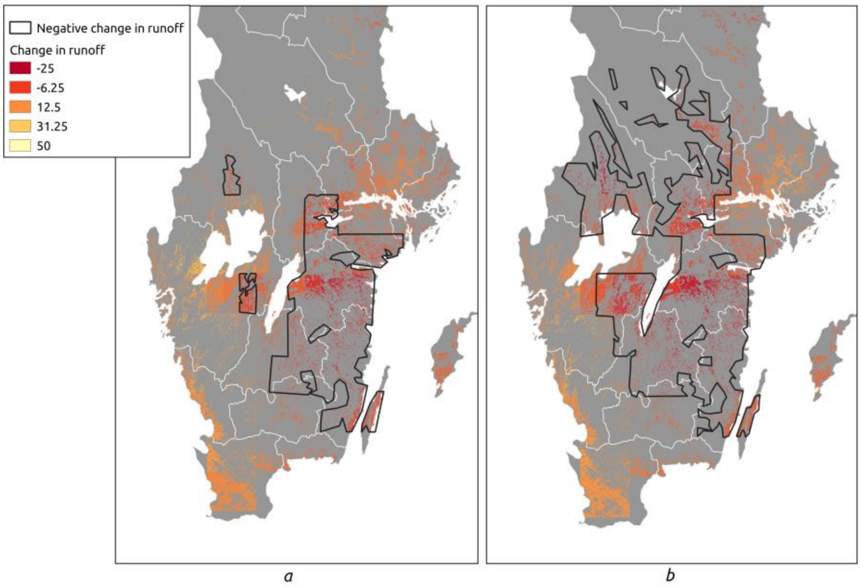


Figure 1: *Change in annual runoff (mm/yr) between 1980-2000 and 2050-2070 for arable land irrigated by groundwater for a) RCP4.5 and b) RCP8.5 scenarios. This area's extent may be much larger than expected as a global dataset for irrigation has been used*

Runoff increases are projected to be more significant for RCP4.5 than RCP8.5, suggesting that groundwater levels remain high over the summer (figure 1). However, there are still multiple areas where the runoff change is negative, where runoff will decrease. The southern tip of Sweden is highly agricultural with a high density of agricultural land. Areas experiencing a future decrease in runoff include Östergötland in both scenarios with Södermandland and Uppland also experience a decrease and potential risk zones of hydrological drought. Although water abstraction is greater for southern Sweden, the runoff change in the rest of southern Sweden is negligible or positive, suggesting that groundwater may remain at least at current levels. As such, abstraction would not put the aquifers at risk, and sufficient water should be available for consumption.

Even so, figure 1 highlights areas with a negative change in the runoff, suggesting lower levels of groundwater. For RCP4.5, arable areas with decreasing runoff are located mainly on the southeastern coastline in Kalmar, Östergötland, and Södermanland. However, under a projected business as usual scenario RCP8.5, the risk area of decreasing runoff concerning current conditions extends further to the north and west, into Värmland, Kopparberg, and Örebro, putting a more considerable amount of the arable land at risk from groundwater shortages, with potential stress on irrigation. If there is not enough water for irrigation, then the yield of crops can decrease. Not only will less water be available for irrigation, but there will be less water in the soils, increasing the strain on crops. The areas highlighted here are areas that adaptive measures should be considered, such as planting new crops that require less water and changing agricultural practices.

A series of climate adaptation measures are presented by Livsmedelsverket (2020), which aim to reduce the negative effects of climate change on drinking water and protect against accidents and extreme weather. However, each municipality's responsibility is to ensure that the standards are met, and the drinking water supply remains constant and contaminant-free. There are both administrative and technical measures that can be adopted to reduce risks to the drinking water supply. The administrative work includes measures to raise awareness, educate and organize activities from a climate change perspective. This work also aims to make key actors aware of drinking water's vulnerabilities and function in society. Measures to raise awareness, educate and organize from a climate perspective include collaboration, both within each municipality and with other municipalities, and on a regional scale. Regular staff training and keeping up to date with current research on climate change and adaptation are essential. An inventory of the resources within the county and municipality should also be undertaken and make clear that all businesses are responsible for their part.

Plans raise awareness of the vulnerabilities posed to drinking water, such as shortages and contamination. These plans include designing general and detailed plans to protect water resources during land exploitation purposes on both regional and local levels. With well-developed plans, the risk of water sources' contamination can be reduced by avoiding the promotion of urban or agricultural development in the locations within high water resources and flood risk (Livsmedelsverket, 2020). Flood risk, landslide, and ground instability maps can be produced to clarify the effects on the drinking water supply, resulting in a vulnerability map of the municipality's water resources. During the physical planning stage, laws need to be considered, such as the Environmental Code, the Planning and Building Act (PBL), environmental quality standards, and water regulations for water protection areas.

Administrative measures also include crisis preparedness of drinking water systems for unwanted climate events. The measures are based on risk and vulnerability assessments. To handle crises effectively the insight into the risk and how different scenarios can escalate the risk should be considered. Preventative measures, access to emergency equipment, and early warning systems must all be available to the municipality to reduce the risk and ensure full preparedness (Livsmedelsverket, 2020).

Access to water will differ from the current situation, with changes in rainfall patterns and precipitation type, which will result in new demands to both drainage and irrigation (Swedish Commission on Climate Vulnerability, 2007). With more extended periods of drought and higher temperatures projected in southern Sweden, one adaptive measure already underway is quinoa's cultivation. Quinoa is a South American crop that is suited to dry conditions, and with a new cultivated variety, it can be grown in Sweden, where farmers are currently testing it in Östergötland. Östergötland is an area where the average temperature will increase, with heat waves within the summer months becoming more frequent.

The number of days with low soil moisture will increase, as precipitation with the largest increase in precipitation occurs in winter and spring (SMHI, 2020). Quinoa is similar to rapeseed and can be harvested using the same methods. However, farmers need to invest in machines used in South America that can sort, polish, wash and dry the quinoa ready to be packaged (Swedish Portal For Climate Change Adaptation, 2020).

4.1.3 Knowledge gap and recommendations

With the population increasing, the demand for food and water will increase, putting further pressure on groundwater for both irrigation and drinking water. Adaptive farming using other crops that require less water, such as quinoa, can reduce water resource stress. However, to offset the risk, adaptive farming will need to increase. A report on the future of farming by Lantmännen (2019) states that there is a potential for a 48% increase in yield by 2050; it is unclear what irrigation data is used in the calculation. Assuming irrigation remains constant, the groundwater's stress will increase as levels drop, and maintaining the same irrigation strategy may not be feasible as water is no longer available. It is essential to know how irrigation strategies will change to assess the risk on groundwater resources. No studies were found on the effect of population growth in Sweden and agriculture. With the current population of 10.3 million increasing to 12 million by the early 2050s (SCB, 2020), higher yields may be required, leading to increased irrigation requirements and, therefore, stress on groundwater levels. Population growth combined with climate change could amplify risks above what they are currently predicted.

Another knowledge gap includes spatial information on the extent of irrigation practices from both surface water and groundwater. For this study, we have used global datasets of irrigation (Siebert et al., 2013), which may not be accurate at Sweden's scale. From a first look, irrigation appears to extend more than expected into central Sweden. Projections on the expansion or intensification of agriculture in Sweden could not be found either. However, these documents may exist but were not accessed or available for this report. These projections are necessary to understand additional risks from the expansion of agriculture northwards or the increasing need for irrigation in South Sweden. These studies could be suggested to the Swedish Board of Agriculture and the Geological Survey of Sweden if they are not already underway.

4.2 Risks for green water or rainfed agriculture

- **There are projected precipitation increases over all of Sweden, which can be positive for Swedish agriculture. However, temperature increases may offset the positive influence of increased precipitation.**
- **The projected increase in evapotranspiration contributes to decreasing soil moisture in large parts of the country (south-eastern and northern Sweden). However, predictions of soil moisture should be interpreted with caution due to these projections' high uncertainty.**
- **Autumn precipitation is not projected to increase significantly over rainfed areas, posing low risks to damages to agriculture.**

In Sweden, the positive effects of climate change are thought to be more important than the negative effects, according to the Swedish Board of Agriculture (Jordbruksverket, 2017). Increasing precipitation, a longer growing season, and better growth for plants due to higher CO_2-levels are examples of positive impacts. Substantial negative impacts on agriculture from climate change are increasing the risk of infestations from pests, agricultural drought during the growing period, and flooding from high amounts of precipitation during harvest time (Neset et al., 2019). Agricultural drought can be defined as a lack of soil water to the point of harming crops (Tian et al., 2018). Rainwater which has infiltrated into the soil and is available to plants, is referred to as green water. Green water is an important water source for both irrigated and non-irrigated cropland (Rost et al., 2008). However, due to a lack of an external source of blue water, non-irrigated crops are most at risk of agricultural drought (Wilhelmi and Wilhite, 2002), and the best indicator of agricultural drought is low soil moisture (Nam et al., 2012). It is difficult to measure soil moisture at the large scale of agricultural lands, and the full consequences of an agricultural drought are often not known until the harvest time (Boken et al., 2005). In Sweden, less than 5 % of the total agricultural area is irrigated in a typical year (Jordbruksverket, 2018c).

4.2.1 Current risks

Northern Europe experienced a drought in the summer months of 2018, which resulted in the loss of crop yields (Beillouin et al., 2020). In Sweden, the temperature was several degrees higher than the monthly mean of 1961-1990 in most of the country, especially during May and July (SMHI, 2020c), combined with lower than usual precipitation in many areas during the summer months (SMHI, 2020c). A period of green water agricultural drought may impact agricultural products' production, for example, feed for animals. During the 2018 drought, fodder prices went up due to shortages, leading to an increased need for importing food and increased slaughter of animals (Statens Veterinärmedicinska Anstalt et al., 2019). Due to the 2018 drought event, financial support was provided to farmers from the Swedish Agricultural Board (Regeringskansliet, 2019), and the estimated total costs for Swedish Agriculture caused by the drought was 6 – 10 billion SEK (Jordbruksverket, 2019). Water available for irrigation was used on crops such as vegetables, fruit, and potatoes, but cereals and oil-producing crops are seldom irrigated in Sweden. Harvest losses were minimized for those who were able to irrigate the crops (Jordbruksverket, 2019). The net income from cereals was 30-40 % lower in 2018 compared to a typical year, caused directly by the drought and the need to use more of the harvest for animal feed than average (Jordbruksverket, 2019). Beillouin et al. (2020) analyzed extreme yield losses in European agriculture during 1990-2018 but could not find any trend during this period. Spinoni et al. (2015) analyzed the occurrences of droughts in Europe during 1950 – 2012 based on historical data and found a decreasing occurrence of droughts in Scandinavia during the period, which could be explained mainly by increasing precipitation.

4.2.2 Risks in 2050 – 2070

Drought frequency and intensity are projected to increase in northern Scandinavia toward the middle of the twenty-first century, mainly under RCP 8.5 and under RCP 4.5 scenarios. Summer droughts are projected to decrease in frequency in southern Scandinavia, but spring and autumn droughts may increase in frequency (Spinoni et al., 2018). The Swedish Agricultural Board is aware of the risk of drought in the summer, especially in south-eastern Sweden, and the increasing need for irrigation (Jordbruksverket, 2017). Shortage of water can lead to increasing prices and shortage of fodder, leading to animals' unplanned slaughter (Statens Veterinärmedicinska Anstalt et al., 2019).

To assess the risks of potential agricultural drought on rainfed agriculture from climate change, we decided to use the estimates of the change in precipitation between future projections of 2050-2070 and the period 1980-2000 during the growing season as a proxy to estimate risks. If the change was positive, an increase in precipitation could be expected, avoiding the risk of agricultural drought in rainfed agriculture. On the contrary, if the change was negative, it implied that there would be less precipitation available during the growing season (April – September), possibly affecting rainfed agriculture. By extracting the projections of future precipitation for the whole country, we find that precipitation is projected to increase in Sweden. The most significant increase in precipitation is projected in the northern agricultural areas and eastern Svealand, while the smallest increase is in south-eastern Götaland (figure 2). In northern Sweden and eastern Svealand, the RCP 8.5 scenario projects a more considerable increase than the RCP 4.5 scenario. The precipitation increase is lower in RCP 8.5 in the central parts of Götaland around lakes Vänern and Vättern.

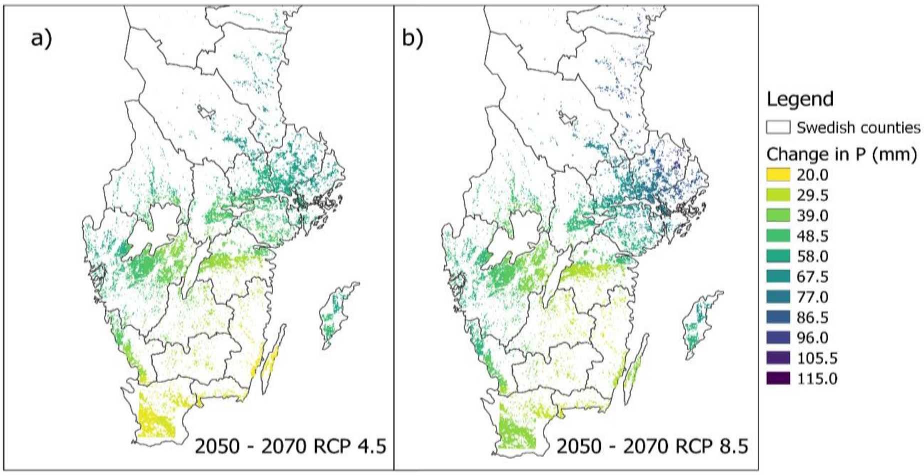


Figure 2*: Change in precipitation during the growing season (April – September) between the reference period 1980 – 2000 and the future period 2050 – 2070 under the two future scenarios a) RCP 4.5 and b) RCP 8.5. The climate data (0.5° resolution) is masked by a raster of agricultural land with a 1000-meter resolution.*

From the perspective of precipitation, there appears to be no risk of rainfed agricultural drought. However, increasing temperatures are likely to increase evaporation which decreases the available water for plants. Evapotranspiration can be estimated as the difference between precipitation and the water discharging either as surface water or groundwater. Following an increase in temperature during the growing season and the entire year across the entire Swedish territory, evapotranspiration is projected to increase under both future scenarios (figure 3). The most significant increase in evapotranspiration is projected in the coastal areas.

Outputs of soil moisture from future climate change projections can be used as proxies to assess changes to rainfed agriculture conditions. However, they present higher uncertainty than the direct climatic projections. The climate models predict soil moisture to decrease on an annual scale in most of the Swedish territory, except for eastern Svealand in both scenarios and the west coast in RCP 4.5 (figure 4). It is difficult to determine how the risk of agricultural drought will change in the future based on the available information. While it is known from past events that droughts can have severe consequences, even in Sweden, climate change is perceived to have more positive than adverse effects on rainfed crop production (Rötter et al., 2012). More research is needed to understand future agriculture conditions better, especially after taking adaptive measures.

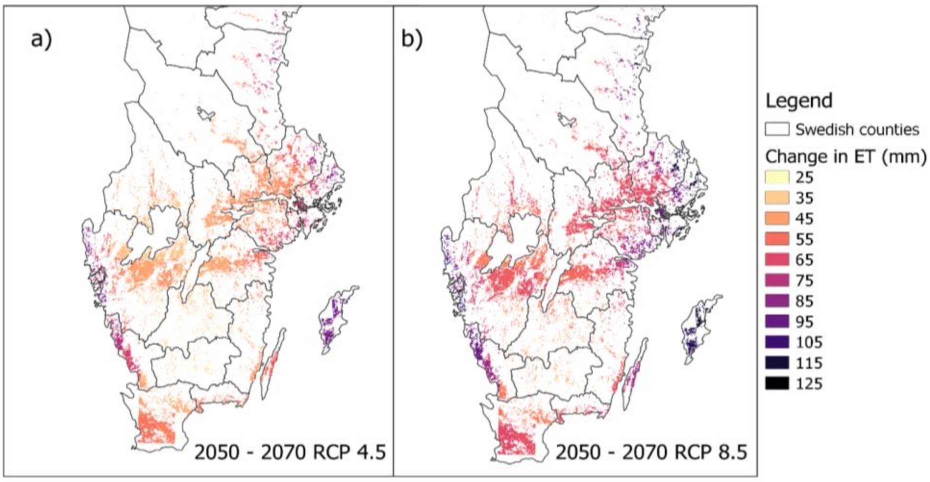


Figure 3*: Change in evapotranspiration (calculated from the difference between precipitation and runoff) from the modeled future 2050 – 2070 under scenarios a) RCP 4.5 and b) RCP 8.5. A raster of agricultural land masks the climate data (0.5° resolution) with 1000-meter resolution.*

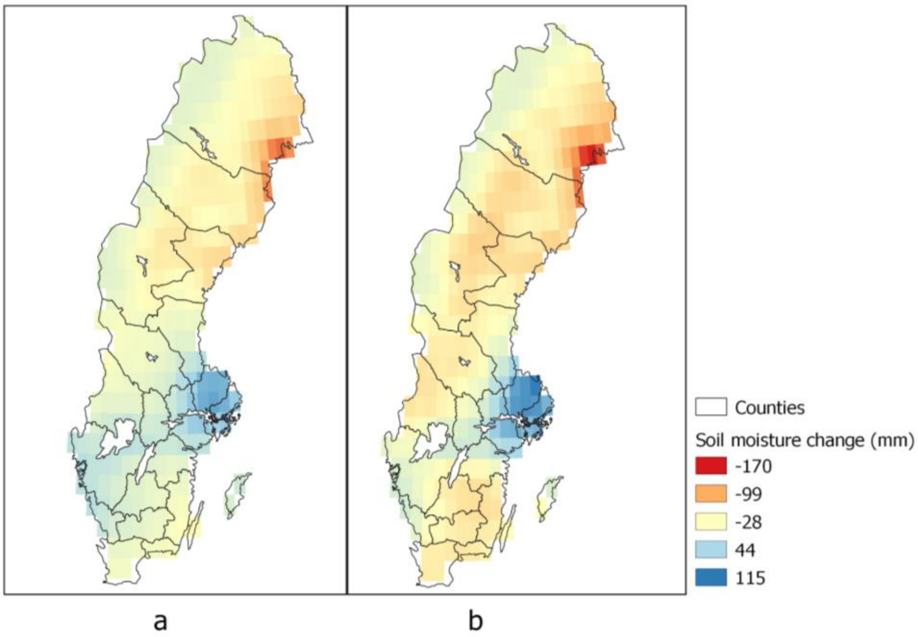


Figure 4*: Annual soil moisture change in 2050-2070 relative to 1980-2000 with a) RCP 4.5 and b) RCP 8.5.*

Increased precipitation during harvest time can make the soil unstable, and using machines over it may compact the soil (Juhola et al., 2017). According to the Swedish Agricultural Board, compaction can be a potential problem, which they highlight can be mitigated by additional or improved drainage systems (Jordbruksverket, 2017).

The autumn precipitation is projected to increase in 2050-2070 under both scenarios over most of Sweden. The increase will be highest in northwestern Sweden, along the border to Norway (figure 5). In the areas with the most agriculture, the increase in fall precipitation is low. Based on average precipitation, it is unlikely that the risks of precipitation damage to crops will increase significantly. However, these data do not show if extreme precipitation will become more or less common in the future.

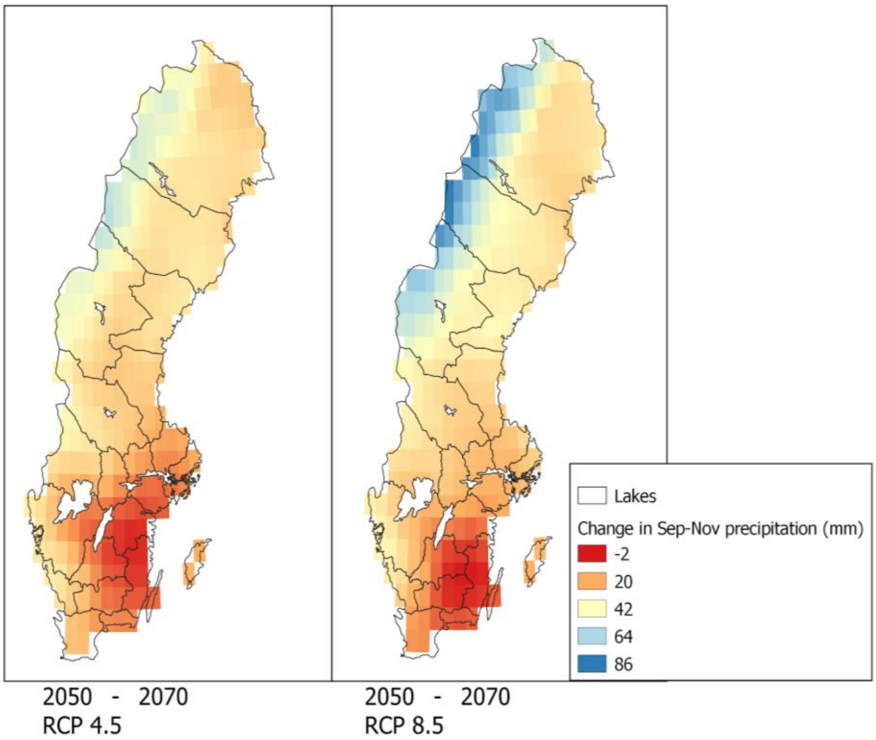


Figure 5*: Change in precipitation in the fall between 1980-2000 and 2050-2070.*

4.2.3 Knowledge gaps and recommendations

Further research is needed to determine how future hydrological changes are likely to affect different rainfed crops. Although increasing precipitation will favor the growth of rainfed crops, especially in areas where the crops can benefit from an increase in water availability, there is particular concern about how concentrated this increase will be. Projections also show decreased soil moisture in north-eastern Sweden that could affect rainfed agriculture in this region, probably due to increased evaporation. However, this result should be interpreted with caution, as estimates of soil moisture from climate projections carry higher uncertainty rates than their climatic variables. The increase in precipitation may translate into more extreme rain events, with most rain falling within specific rain events, with higher erosive potential, leading to higher soil loss in current conditions. This higher intensity and energy of rain events may also favor flooding in cultivated areas resulting in water-logging that may not favor specific crops. A recommendation to understand this risk is to estimate the increase in energy and intensity of rain events for the future in current rainfed agriculture areas. Knowledge of the Swedish government's plans to expand agriculture could also enable a more profound assessment of how future agricultural areas may cope with future precipitation changes.

4.3 Pests and damages to agriculture and forestry

- **Increased suitability for insect pests in northern Swedish forests**
- **Increasing problems with insect pests in agriculture in southern Sweden due to rising temperatures**

4.3.1 Current risks

From a mitigation viewpoint, increased production of forest products is beneficial, as this may offset production from fossil fuels emitting other greenhouse gases (Lundmark et al., 2014). Increasing temperatures will likely increase forest growth in Swedish forests and timber production; however, this is not fully proven to date (Jaramillo et al. 2018). Furthermore, there are also increasing risks of damages to trees associated with climate change (Keskitalo et al., 2016). Insect damages in forestry have been increasing in Sweden over the past century due to rising temperatures during winter and summer and forest management changes (Tudoran et al., 2016).

It is likely that by 2050 the damages caused by pests will increase in Sweden (Sari Kovats et al., 2014). Currently, Swedish agriculture has been affected mainly by weeds and fungus diseases, but with a warmer climate, insects' problems are likely to increase (Jordbruksverket, 2012a). Many of the fungus diseases that are present today are also likely to increase in warmer temperatures, although some will be disadvantaged by drier summers (Jordbruksverket, 2012a). During the 2018 drought, the fungus (mold) infestation was lower due to the drought, and thus, the use of fungicides was lower. Nevertheless, the infestation of insects was higher for some crops (Jordbruksverket, 2019). A longer warm season can extend the activity of different kinds of pests (Sari Kovats et al., 2014), and the spread of viruses to plants from insects is expected to increase (Jordbruksverket, 2012a). The vectors benefit from higher temperatures and a long warm period allows them to go through more generations per year (Roos et al., 2011). There are examples of insect distribution expanding north with rising temperatures, which is likely to continue (Lamichhane et al., 2015). Milder winter temperatures are also likely to favor insects' survival during winter (Lamichhane et al., 2015). Grünig et al. (2020a) modeled pest insect species' distribution and found a threshold when the coldest month's minimum temperature was above -3 °C. Warm weather could increase the chances of survival for insect species causing problems with pests for European agriculture. Droughts also increase trees' sensitivity to pest infestations (Brecka et al., 2018; Venäläinen et al., 2020).

4.3.2 Risks in 2050 – 2070

Following the findings of Grünig et al. (2020a), we used the mean minimum daily temperature from January to March as a proxy to assess this risk (figure 6). During the reference period 1980 – 2000, there was only a small area of the country with mean minimum daily temperatures above -3 °C from January to march, located in southwestern Skåne. However, since winter temperatures will increase, the mean minimum winter temperatures above -3 °C would increase under future scenarios RCP 4.5 and RCP 8.5. Under the RCP 4.5 scenario, the western coast, the southern tip (Skåne and Blekinge), and the islands Öland and Gotland will experience mild winters with minimum temperatures above - 3 °C. For the RCP 8.5 scenario, the mild winters will also cover the eastern coast up to the latitude of the city of Stockholm and the inland and coast of southern Sweden. Minimum winter temperatures are likely to rise in the future, enabling the survival of insect species in southern Sweden's agricultural regions. There is also a high risk of new pests and diseases coming into the country when the climate changes and when new crops are introduced (Grünig et al., 2020b; Jordbruksverket, 2012a; Lamichhane et al., 2015). Jordbruksverket (2012a) identified possible insect, fungus, bacteria, and weed pests that are not present in Sweden today but may become a problem in the future. For Swedish agriculture, risks associated with pests are expected to be highest in the country's southern parts, as seen both by the analysis and the results of other studies (e.g., Grünig et al., 2020b, Eckersten et al., 2008).

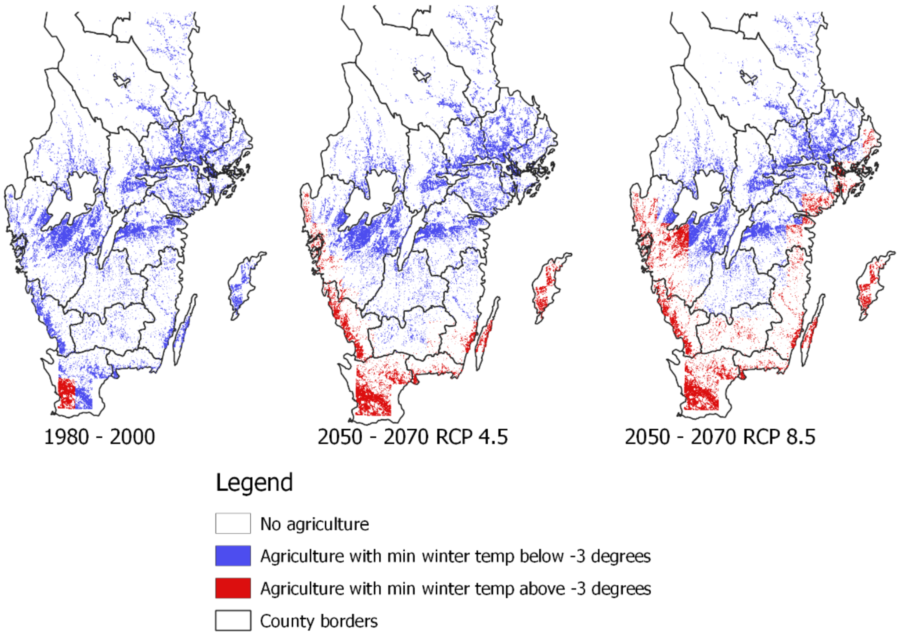


Figure 6*: Mean minimum winter (January - March) temperatures in agricultural land for the current and future projections under RCP4.5 and RCP8.5 scenarios. The resolution of the agricultural land is 500 meters, and the climate data resolution is 0.5 degrees.*

Higher exposure to pests in agriculture will likely lead to increased pesticide usage (Wivstad, 2010). The development of organic agriculture and alternative methods to pesticides and can offset this trend significantly if political and economic forces enhance or regulate these changes (Wivstad, 2010). Increased cultivation of grains that require little or no pesticides and increased transition to organic farming of crops that generally require much pesticide are examples of methods to decrease pesticide use. Natural pest control is an ecosystem service for both vertebrate and invertebrate animals. Since pesticides are often harmful to natural predators, natural pest control from vertebrates in southern Sweden can be favored by a warmer climate (Civantos et al., 2012).

Climate warming is believed to favor many insects, which could increase damage to trees and thus negatively affect forestry. Hof and Svahlin (2016) modeled the geographical distribution of climate suitability in 2070 for 30 species of potential insect pests for forestry in northern Sweden. The study described that the current climate allows the distribution of insect species mainly near the coast and around large water bodies such as Storsjön in Jämtland. In 2070, under both RCP 4.5 and 8.5 scenarios, most species' potential geographical distribution would increase to cover most of Norrland. The pest species' movement is in a north-western direction in northern Sweden (Grünig et al., 2020b), and the economic damage from pests in forestry is thus likely to increase and the insect distribution to spread faster in the more southern areas (Hof and Svahlin, 2016). Skogsstyrelsen (2020) has made estimates of risks within the forestry industry in Sweden to find that the most significant increase in costs is associated with infestation of spruce bark beetles, in 2050 and 2100, compared to the present period 1990-2010.

4.4 Groundwater contamination

- **Regions with high groundwater fluctuation in northern Sweden, are more at risk of contamination due to the mobilisation of heavy metals within the topsoil.**
- **With conditions becoming more favourable for agriculture further north, the risk of contamination from pesticide use increases.**

4.4.1 Current risk

Contaminated soil is a problem globally, and the European Environmental Agency has estimated 340,000 contaminated areas of land within Europe (EEA, 2020). There are approximately 25,000 contaminated sites in Sweden (Swedish EPA, 2017), and approximately 1,300 of these sites are considered at significant risk in terms of the environment or human health and require remediation measures (SGU, 2020). The Swedish Parliament has produced guidelines for future remediation of contaminated sites by adopting the environmental quality objective called A Non-Toxic Environment. The objective aims to ensure that the occurrence of human-made infrastructure or extracted materials or substances does not represent a threat to human health or biological diversity (Naturvårdverket, 2020). The primary sources of contamination include heavy metals, such as lead and arsenic, which predominantly come from atmospheric deposition of traffic emissions, mining, agriculture, release from landfills, other industrial activities, and accidental spills of contaminant substances (Barth et al., 2009; Tóth et al., 2016; Jarsjö et al., 2017a). Lead and arsenic represent both high and low mobility of heavy metals within soils and groundwater, with arsenic being the most mobile (Jarsjö et al., 2020). The typical outcome from a contaminated site is a vertical gradient of metals in the soil, where the topsoil has the highest concentration that decreases with depth. Contamination uptake from the soil through crops and direct contact with the soil can lead to human exposure (Raguz et al., 2013). In turn, waterborne spreading through coupled groundwater-surface water systems can affect wells and drinking water (Mulligan et al., 2001; Törnqvist et al., 2011). Current population densities and industries, and the resulting contamination sites, are located near water sources, further increasing the risks of exposure and contamination (Destouni et al., 2010; Persson et al., 2011; Andersson et al., 2014).

The expected shift of temperatures suitable for agriculture northwards will improve crop conditions and productivity in Sweden and other Nordic countries (Trnka et al., 2011). Changes will probably be made to crop selection and cultivation to adapt to the shift in growing seasons (Olesen et al., 2011). The spatial and temporal distribution of crops, and subsequently, weeds will also be affected by the climate shift. Subsequently, pesticides will be used to a more considerable extent, leading to leaching and contamination of both surface and groundwater resources. Since groundwater can be slow and expensive to remediate (Vonberg et al., 2014), it is essential to protect groundwater resources. Herbicides tend to be more mobile and hence pose the most significant risk to groundwater contamination from agricultural practices. Climate change can, directly and indirectly, affect herbicide leaching by changes in precipitation and temperature and land and pesticide use (Steffens et al.,. 2015).

Dissolved organic content in water contributes to the brownification of water as water becomes more coloured. Brownification is an environmental risk to the ecology of freshwaters as it affects the water quality and the function and structure of aquatic ecosystems (Solomon et al.,. 2015). Higher runoff is connected to higher transport of organic material (Svenskt Vatten, 2007), and residues of dissolved organic content interfere with the treatment process of drinking water and increase the risk of other harmful organic compounds in the water (Kritzberg et al., 2020). It is not fully clear how climate change and land-use change affect brownificaiton (Kritzberg et al., 2020). The water colour in the western part of Lake Mälaren has become darker over the past decades, especially during the spring when the humus transports are large (Sonesten et al., 2013).

4.4.2 Risks in 2050-2070

There are concerns that ongoing hydroclimatic changes can lead to aggregation and increase current contamination risks and affect transport pathways to drinking water wells and surface water (Schiedek et al., 2007; Colombani et al., 2016; Jarsjö et al., 2017b). The effect of rising temperatures across the globe (Field, 2014) will impact the geochemical and physical properties of the contaminated soil interactions with groundwater (e.g., Augustsson et al., 2011). Recharge of groundwater levels will be affected by changes in the intensity and frequency of rainfall (Jyrkama and Sykes, 2007), which affect contaminant leaching and subsequent transport (Barth et al., 2009). The Arctic and Northern Europe are projected to see an increase in mean annual precipitation (Olsson and Foster, 2014) and rising temperatures in high latitude regions. Groundwater levels are vulnerable to the alteration from changing climatic conditions, both seasonally and annually (Rodhe et al., 2009; Sundén et al., 2010; Vikberg et al., 2015).

Warmer winters at high latitudes will lead to more extended periods with the unfrozen ground, snowmelt occurring earlier in the year, and precipitation in the form of rain rather than snow (Vikberg et al., 2015). These changes will increase the amount of potential groundwater recharge and, subsequently, groundwater levels (Sutinen et al., 2008; Okkonen and Kløve, 2011). Vikberg et al. (2015) predict that groundwater levels over winter will increase in Sweden. However, warmer temperatures with higher evaporation, combined with less recharge and more strain on groundwater resources, will decrease groundwater levels during summer (Okkonen and Kløve, 2011), with more significant seasonal variations and increased fluctuation of groundwater levels.

Jarsjö et al. (2020) conclude that for regions where the average groundwater level or its fluctuations are expected to increase, there is a risk that heavy metal contamination in the topsoil will become mobilized and spread to groundwater systems. Climate change indirectly increases the transport of arsenic as the groundwater levels fluctuate. Lead is relatively stable in soil but is sensitive to increased groundwater levels and fluctuations due to the facilitated transport of lead particles within the highly conductive topsoil. Therefore, elements that increase solubility in the soil's upper layer are more susceptible to climate-driven groundwater change.

Weeds and pests may be expected to shift northwards due to faster reproduction and increased survival rates (Patterson et al., 1999), which will affect the health of crops in Sweden (Roos et al., 2011). With increased pests due to climate change, more pesticides will be required to maintain crop health, leading to the increased risk of groundwater contamination resulting from pesticide leaching (Bloomfield and Marchant, 2013; Henriksen et al., 2013). The fate of the pesticides can be influenced by climate factors such as increased temperature and precipitation (Nolan et al., 2008). The direct effects of climate change do not necessarily result in negative impacts with increased temperature leading to higher contamination degradation rates. However, increased precipitation will generally lead to increased leaching (Bloomfield et al., 2006). Other influences on pesticide pathways include indirect effects of climate change, such as a change in crop growing patterns (Olesen et al., 2011), pesticide use (Koleva et al., 2009), and soil type and conditions such as soil thawing (Stenrød et al., 2008). Work by Steffens et al. (2015) portrayed the importance of indirect effects of climate change on herbicide leaching, as changes in land patterns and herbicide use will double the area at risk from groundwater contamination. Areas with medium to high clay content within the soil are at higher risk in the future if herbicide use increases (Steffens et al., 2015).

In order to assess risks of potential contamination proxies, we used projections of snowmelt, minimum annual temperature, change in the runoff, and precipitation.

Increased annual snowmelt is represented by the blue, and it can be seen in a band that runs from central to northern Sweden through Jämtland, Västerbotten, and Norrbotten. Snowmelt will increase recharge and increase groundwater levels, subsequently increasing the risk of heavy metal mobilization from the topsoil into the groundwater systems. A decrease in the annual change in snowmelt can be observed in southern Sweden, limiting groundwater contamination. The decrease is probably related to the occurrence of less snow. The risk of contamination is most significant when large fluctuations in groundwater occur, and reduced snowmelt change will mean less recharge and ultimately slow changes in groundwater level. The decrease in snowmelt in the south could result from warmer annual temperatures, hence less precipitation as snow in the winter.

Figure 7 shows the reference period's (1980-2000) annual minimum temperature, and figure 8 the change in annual minimum temperature for the RCP4.5 and RCP8.5 scenarios. There is currently an average annual minimum temperature in Sweden ranging from 6 °C in the south to -12 °C in the north. For scenario RCP4.5, the minimum temperature will rise by +2 °C in southern Sweden and +4 °C in the north. The increase in minimum temperature is even more significant for RCP8.5 and will result in precipitation occurring as rain rather than snow later into the year (Xu, 2000). Warmer temperatures result in more water recharging into the groundwater as it is not stored as snow, causing higher-than-average groundwater levels and fluctuations. These changes can activate the topsoil and mobilize contaminants that would otherwise be stable. Northern areas would be more at risk from groundwater contamination by groundwater fluctuations. Although these areas are not agricultural, freshwater and drinking water supply can still be contaminated, which can have a societal and ecological impact on mining or industrial activities that are to be developed in the future as temperatures increase. Drinking water wells can become contaminated, and water quality deteriorates. However, it is essential to note that soil type, geology, and other industrial pollution could severely affect the contamination of groundwater and must be considered in a more detailed, site-specific study. Snowmelt and temperature can provide a good proxy for areas where contamination can occur due to fluctuation of groundwater levels and subsequent mobilization of heavy metals within the topsoil. However, to fully understand the contamination potential of a source and the ability to get into groundwater systems more, detailed studies are required. The studies must deepen our understanding of precipitation, hill slope, infiltration, soil types, bedrock, pesticide and herbicide sources and amounts, and irrigation for specific sites to quantify the risk entirely.

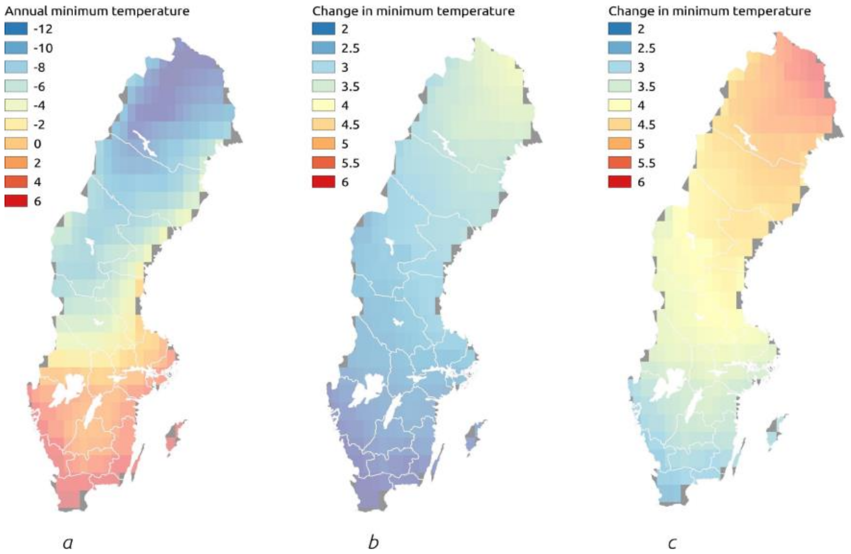
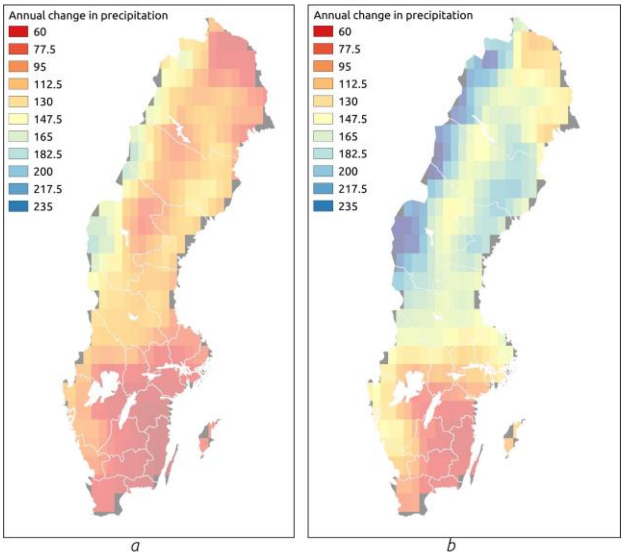


Figure 7: *Temperature in the reference period and* Figure 8*, a) change in temperature (°C) between 1980-2000 and 2050-2070 in RCP4.5 and (b) RCP8.5*

Figure 9 shows the annual change in precipitation for RCP4.5 and RCP8.5, where an increase can be seen for both scenarios. Although a minor increase is observed for the RCP4.5 scenario compared to the RCP8.5 scenario, both scenarios show positive changes, representing a general and wide-spread increase in precipitation in Sweden. Areas with the smallest change in precipitation are in the southeast of Sweden for both cases. For climate change projection RCP4.5, a large extent of southern Sweden has more minor precipitation changes than the rest of the country. This pattern is similar in RCP8.5; although the area is now smaller, the precipitation change remains the same. Areas with a significant change in precipitation present the most risk as more precipitation can result in more significant recharge of groundwater and subsequently increased fluctuation and groundwater levels. If groundwater reaches the topsoil, metals can be mobilized and contaminate groundwater systems, potentially polluting the drinking water supply. For RCP4.5, the areas with the greatest change in precipitation, and subsequently the most at risk, are along the western border with Norway and the east coast north of Uppland county. These risk areas are the same for RCP8.5 but increase as the change in precipitation is greater. The increased change in precipitation for RCP8.5 also puts areas of the west coast of Sweden at a greater risk than RCP4.5. Counties of Västernorrland, Västerbotten, and Norrbotten are at risk on the east coast, with the latter being at risk on the west border.



a

b

Figure 9: *Annual change in precipitation (mm) between 1980-2000 and 2050-2070 for RCP4.5 (a) and RCP8.5 (b)*

Figure 10 shows the annual change in runoff across Sweden for RCP4.5 and RCP8.5, where it can be observed that the greatest change in the runoff for both projections is along the western border with Norway. The south of Sweden does not see the same extent of change, and the change remains similar between the two future scenarios. However, the north of Sweden shows a significant change between the climate change projections, with RCP8.5 showing a more considerable increase in runoff change. It should be noted if there is a pollution source, such as a heavy metal concentration above average in the soil, within an area where a significant increase in both precipitation and runoff is observed, then this area could be considered high risk. The increased risk is related to more water infiltrating through the soil from precipitation and recharging the groundwater resulting in water levels fluctuating and increasing the risk of heavy metal mobilization from the topsoil. Changing groundwater levels also change the local hydraulic gradients, leading to more widespread transport of contamination. The areas where there are both high runoff and high precipitation changes are along the Norwegian border and an area 70km inland of Sweden's north-eastern coast. These are areas where the conditions are most favorable to groundwater contamination, but a contamination source is unknown. With conditions becoming favorable for agriculture further north, increased pesticide use might provide a source of contamination. Further studies in these areas are needed to determine the extent of pollution and whether this affects flora and fauna. If the groundwater is getting more contaminated but is not relied on for humans or the ecosystem, it no longer presents a real risk.

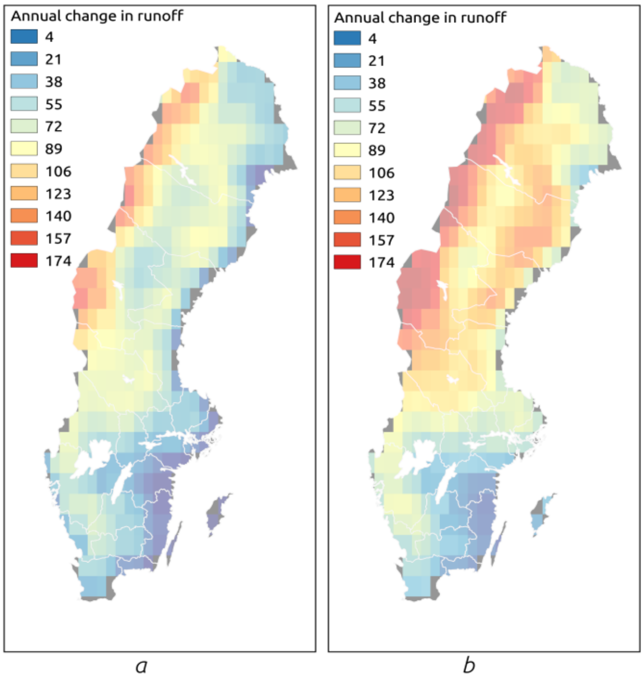


Figure 10: *Change in runoff (mm) between 1980-2000 and 2050-2070 for RCP4.5 (a) and RCP8.5 (b)*

4.4.3 Knowledge gaps and recommendations

Due to the site-specific nature of risks related to groundwater contamination, it is not feasible to have countrywide adaptive measures for such risk. However, a set of guidelines can be produced, and groundwater monitoring can allow the effects of climate change on groundwater contamination to be further understood. A joint water project by two municipalities is running in Skåne, Bromölla Municipality and Blekinge, Olofström Municipality, to secure access to reserve water from Olofström, with Olofström, in turn, having access to cleaner and safer water supply from Bromölla. Both municipalities have issues with the quality of their drinking water. The municipalities produced a joint agreement for water supply in 2012, enabling the construction of a pipeline between the counties and using Bromölla's groundwater reservoirs to supply Olofström. By creating a joint water supply strategy, both municipalities have seen benefits. For the case of Bromölla, it has been beneficial from a financial point of view and to obtain reserve water in the event of a water shortage. For Olofström, large quantities of clean, safe water can now be obtained from Bromölla. The cost of building the pipelines, waterworks, and groundwater wells is divided between the two municipalities, with the division being determined by the actual water use.

Another adaptation and mitigation case is along the Höje River (Swedish Portal for Climate Change Adaptation, 2020). The Höje River Project collaboration started in 1991, intending to protect the water within the entire drainage basin. A holistic view and sharing the costs allowed the initiation of tangible measurements across the municipalities and the investment into new major projects, an approach that may become more valid as climate change presents further challenges.

Lack of knowledge regarding how changing hydraulic gradients will affect flows of water on a larger scale. The hydraulic gradient is defined as a vector gradient between two or more hydraulic head measurements over the flow path's length, and the distribution of hydraulic heads through the aquifer determines where the groundwater will flow. It is not clear if there will be a potential risk of contamination when large bodies of water lose volume. Due to the site-specific nature of groundwater contamination problems, large reservoirs should be studied and the risk for that particular case assessed.

Although the southwestern part of Skåne is strongly dominated by agriculture, there has always been a low level of pesticide and nutrient leaching from intensely cultivated land into adjacent watercourses. However, with increasing temperatures, the leaching amount can increase as milder winters result in the ground remaining unfrozen and precipitation falling as rain. Compared to uncultivated land, agricultural land releases rainwater faster, leading to increased leaching and the potential for flooding. When it comes to leaching, the importance of the choice of crop, soils, fertilization, and tilling measures should be studied based on anticipated changes in the climate, including the climate's variability. Research from Lewan et al. (2009) suggests that restricting pesticide applications' timing to avoid wet soils in autumn could potentially reduce the pesticide losses by a factor of two or three and would be better for the farmers rather than a restriction based solely on the date. Risks to surface water in spring can also potentially be reduced by the same factor by avoiding the application of pesticides if the 5-day weather forecast predicts high levels of precipitation (>10 mm). Since control measures of water quality cannot be confined to each municipality boundary as each measure will have an effect only downstream of the municipalities, a holistic approach is required to mitigate the risk of all municipalities affected.

4.5 Sea level rise and salt intrusion

- **The south-eastern coast of Sweden may be at risk from saltwater intrusion due to sea-level rise and changing groundwater level**
- **Low lying lands in southern Sweden, and possibly Gotland and Öland, are at risk of inundation, resulting in loss of agricultural land and ecosystems.**

4.5.1 Current risks

It is a fact that sea levels are rising due to melting ice from the Greenland ice sheet and the West Antarctic Ice Sheet (Hanna et al., 2005; Meier et al., 2007; Stroeve et al., 2007). The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations that is dedicated to providing the world with objective, scientific information that is relevant to understanding the scientific basis of the risk of human-induced climate change, its impacts on ecology, politics, and economics, and providing possible response options. According to the IPCC, the pace of sea-level rise increases, and a global mean sea level rise of 0.63 m is likely to occur up to 2100 and continue rising beyond (IPCC, 2014). Sea level rise can range from 52 to 98 cm in the scenario RCP8.5 for Sweden. On a more global scale, however, the Greenland Ice Sheet loss will result, with high levels of confidence, in a mean sea level rise of 7 m (IPCC, 2014). However, the exact amount and pace of sea-level rise are uncertain (Nicholls et al., 2011). In Sweden, the net effect of sea-level rise, assuming a global sea-level rise of 88 cm in 2100, is 80 cm in southern Sweden up to Östergötland, 50 cm in central regions up to Uppsala, and 20 cm in the northern regions (Swedish Commission on Climate Vulnerability, 2007). Postglacial rebound in Sweden will mean that local sea-level rise will be lower than global levels in its central and northern parts. Since land rise is minimal in the south, sea levels will rise the most in the country. The estimates of land uplift are based on the Swedish National Land Survey (Ågren and Svensson, 2007).

4.5.2 Risks in 2050-2070

One effect of rising sea levels on coastal regions would be seawater intrusion into coastal aquifers used for drinking water. For the Baltic Sea, studies have generally focused on climate change effects on surface water rather than groundwater resources (Andréasson et al., 2004; Graham, 2004). One of the first studies addressing the effect of climate change on seawater intrusion into coastal aquifers was Sherif and Singh (1999). Although this study was not carried in Sweden, it concluded that a 50 cm in sea level could result in an additional intrusion of 9 km into the Nile Delta aquifer. They also concluded that sea-level rise would impose additional seawater heads at the coast, and therefore, more seawater intrusion must be anticipated. Changes in the location of the freshwater-saltwater interface of coastal aquifers can be affected relatively far inland with just a slight increase in sea level. Observations from Rasmussen et al. (2013) show that the volume and thickness of coastal freshwater aquifers surrounding the Baltic Sea can decrease considerably under changing climatic conditions. Due to the crystalline rocks, seawater's intrusion into freshwater aquifers is usually limited to a zone approximately 100 m wide along the coastline. However, where sedimentary rock formations occur in southern Sweden and the islands of Öland and Gotland, seawater intrusion can even reach aquifers located further away from the coast. Highly fractured limestone aquifers with karstic structures may be the reason why 61% of all groundwater wells in Gotland can suffer from salt intrusion (Olofsson, 1996). In areas where sandy sediments with high permeability are hydraulically connected to the sea, saltwater has intruded into the aquifer when freshwater has been extracted for municipal supply. There is also the risk of direct inundation of coastal wells from sea level rise, rendering their freshwater resource unusable.

The drinking water supply and quality are affected by sea level rise and the agricultural and industrial sectors. Sea level rise can lead to flooding of the land. The flooded land also has the potential to release contaminants from within the soil. The flood risk areas within Sweden were defined in a 2018 report by the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, 2018), which stated that 25 areas were at risk, with 16 located in coastal areas. The risk of flooding increases along the coastal areas due to the projected increase in sea level. Most risk areas are located in southern Sweden, meaning that adaptation measures should be prioritized in these areas.

Rising sea levels also induce increased erosion along the south coast, consisting of easily eroded soils and sand. Frequent erosion already occurs along the coast of Skåne, where the coastline has retreated in some locations over 150 m in the last 30 years (Rankka and Rydell, 2005; , with a risk for residential properties built along the coast. Waterside housing is sought after, and an increasingly large proportion of construction in southern Sweden is located within the coastal zone (5 km from the coast). More than 30% of Swedish buildings are in the coastal zone (Swedish Commission on Climate Vulnerability, 2007), and the proportion of buildings within 100 m of the shoreline has doubled from the 1970s to the 1990s (Boverket, 2009). Over 150,000 buildings worth 220 billion SEK are located in areas that are susceptible to erosion from a sea-level rise of 88 cm (Swedish Commission on Climate Vulnerability, 2007), and the cost of protection against beach erosion along the 220 km stretch of coastline is estimated at 2.7-5.4 billion SEK (Swedish Commission on Climate Vulnerability, 2007).

The coastal protection policy in Sweden focuses on spatial planning. The first 100 to 300 m of the coast must be kept free from exploitation according to the Nature Conservation Act of 1974. It is the municipality’s responsibility to comply with the law within spatial planning. Additionally, new development projects must have safety margins to protect against higher future water levels and erosion. Areas of the coast not required by private or public interests become managed areas (Dronkers and Stojanovic, 2016).

The future RCP4.5 and RCP8.5 scenario sea level data from SMHI (2019) was used to assess the potential threat of sea-level rise on coastal aquifers by saltwater intrusion and the subsequent effect on drinking water wells. The database for drinking water wells is from SGU (2020) and was filtered to represent only wells used for drinking water. For each scenario, both the average and the high sea level (SMHI, 2019) were used to calculate the wells put at risk. The household drinking water wells within 300 m and 500 m were calculated for each new sea level, similar to Eriksson et al. (2018). With increasing distance from the Baltic sea, the risk of saltwater intrusion decreases as the transition zone between salt and freshwater deepens. Two buffer zones were used, the first from the coastline to 300 m inland and the second 300 m to 500m from the inland, with the latter buffer zone representing a higher risk zone. Table 1 shows the number of wells within each buffer for future projections.

Interestingly, under the RCP4.5 scenario, 3% of coastal drinking water wells will be put at risk. For RC, this number is lower with only an additional 2% of coastal wells within 300 m of the coastline, although we would have expected a more significant number of wells for this Business as usual scenario. A smaller increase in the number of wells at risk between 300 and 500 m can be observed, ranging from 1.5% for RCP4.5 up to 2% for RCP8.5. However, since distance alone is not a sufficient risk indicator for salt intrusion, groundwater level data have also been used in this report and change in summer runoff and precipitation for both projections.

The groundwater level proxies used include CORDEX data for change in summer runoff and precipitation for both projections. Lower precipitation reduces the aquifer's recharge and results in an increased risk of saltwater intrusion (Rushton, 2004). Lower groundwater levels reduce the hydraulic gradient and freshwater flows towards the Baltic, further increasing saltwater intrusion risk (Klassen and Allen, 2017). The summer months are a period where groundwater levels are naturally low already.

Table 1: *Wells within 300m and 500m of the coast for the present and varying sea-level projections RCP4.5 and RCP8.5 for 2050*

	Number of wells located less than 300 m from the coast	**Number of wells located in the buffer between 300 and 500 m from the coast**
Current	16,910	4952
Average RCP4.5	17,480	4709
High RCP4.5	17,555	4692
Average RCP8.5	17,318	4924
High RCP8.5	17,389	4934

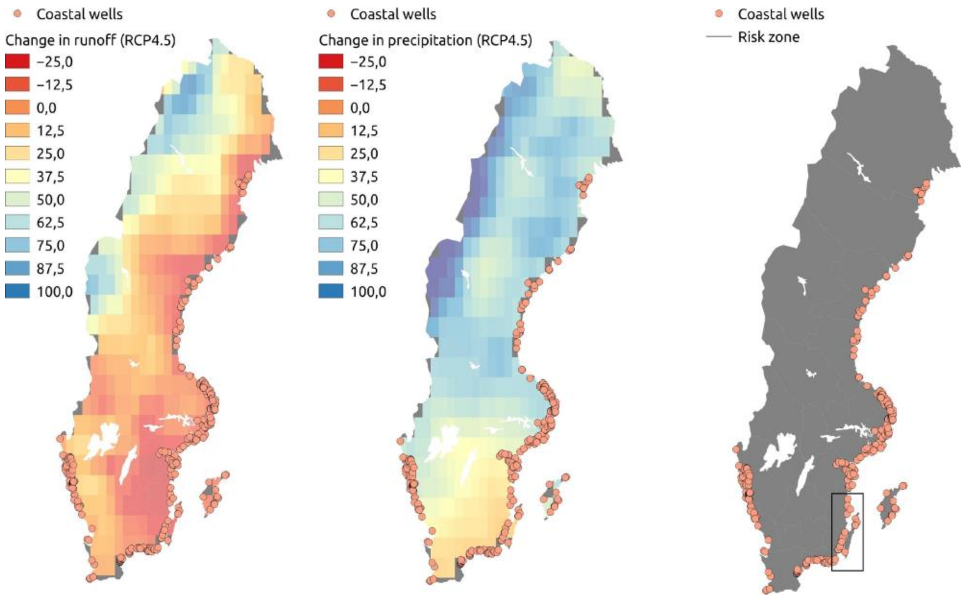


Figure 11*: a) Change in runoff (mm) and b) in precipitation (mm) for summer conditions between 1980-2000 and 2050-2070 in scenario RCP4.5. c) Risk zone for RCP4.5 sea level rise is shown with the black box*

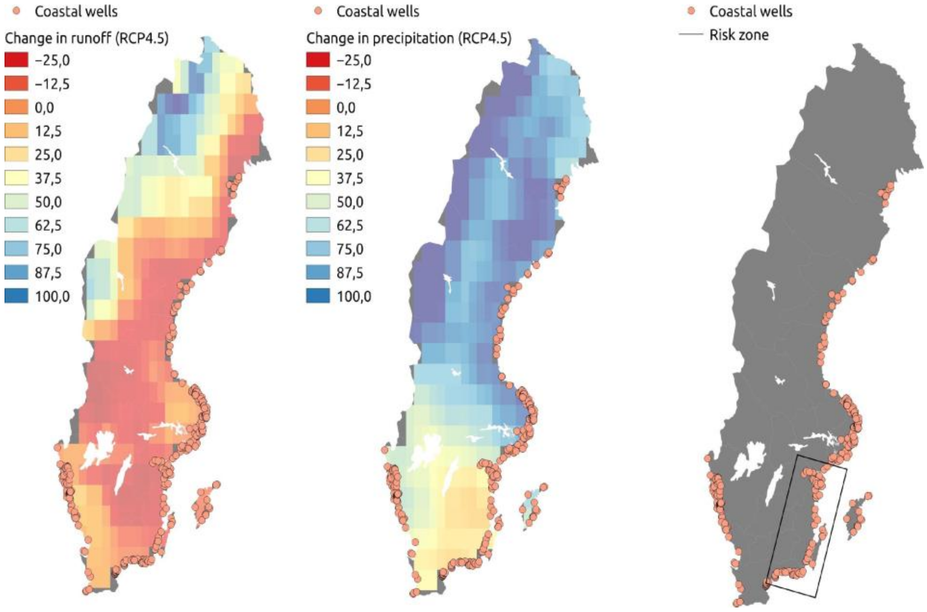


Figure 12*: Same as Figure 11, but for the scenario RCP8.5*

Figures 11a and b show the projected change in runoff and precipitation for the RCP4.5 scenario. The change in runoff during summer shows the majority of the eastern coastline of Sweden with decreasing runoff. In coastal areas with a decrease in runoff and precipitation, groundwater level changes can be assumed to decrease as well, increasing the risk of saltwater intrusion as the hydraulic gradient is reduced. Drinking water wells are most at risk in south Sweden, posing a threat to the area's drinking water. The projected changes in precipitation and runoff for RCP8.5 (figure 12) are similar to those of RCP4.5 shows more decreasing runoff on the east coast, probably increasing the risk of salt intrusion. This study identifies a coastal buffer with a risk of saltwater intrusion due to sea-level rise(Fig. 11c and 12c). The area could be better mapped using other parameters such as soil type, elevation, distance to lakes, and annual average precipitation (Eriksson et al., 2018).

A study on the risk of sea-level rise by Eriksson et al. (2018) used these parameters and used a weighted average to develop detailed risk maps of Öland. Comprehensive studies by Eriksson et al. (2018) and Ebert et al. (2016) analyzed the effect of sea-level rise on Öland and Gotland, respectively. These studies looked at a hypothetical sea-level rise of 2 m, which is more than is projected for the future time frame used in this report of 2050-2070. Eriksson et al. (2018) concluded that with a future sea-level rise of 2m, 5% of the land area of Öland would be inundated along with 3% of wells, including wells used for small farms, summer houses, and for geothermal energy. As such, sea-level rise will be costly in areas that are more pronounced around densely populated areas where property loss and damage could be expensive. In the long term, Öland could suffer from the decrease in tourism as touristic areas are lost to sea-level rise. The north of Öland is more at risk of saltwater inundation as the land has a low elevation and relatively low annual precipitation. High-risk saltwater intrusion areas contain 17.5 % of the wells; therefore, the risk map produced by Eriksson et al. (2018) could be used to find locations for drinking water wells in areas of reduced risk.

For a 2 m sea-level rise on Gotland, 3 % of the land will be inundated, affecting touristic and natural value areas (Ebert et al. 2016). The affected areas include 53 % of endangered plants and species habitats, 35 % of camping areas, 60% of protected stack areas, and 60 % of all shore meadows. Sea level rise would directly inundate 231 wells and place many more wells within the high-risk zone for saltwater intrusion. Some features will be irreversibly lost, for example, loss of freshwater coastal aquifers due to saltwater intrusion, others could be moved inland, but this will come at a higher cost. Holistic approaches will be needed to study the future consequences of sea-level rise to identify risks for particular regions and take the appropriate actions (Ebert et al., 2016).

Sea level rise and saltwater intrusion pose risks that need to be considered and managed. The Ystad municipality is already facing issues of coastal erosion. The rate of erosion is expected to increase as the sea rises. Ystad is located by the sea, and the coastal areas away from the city are essential for Ystad municipality's natural environment and economy. The first large-scale beach nourishment project in Sweden took place in 2011, where 100,000 cubic meters of sediment were extracted from the seabed and placed on the two most affected beaches, Löderups Strandbad and Ystad Sandskog. Beach nourishment preserves the beach's natural and recreational values while acting as natural protection against coastal erosion. Ystad has budgeted 10 million SEK every three years to implement beach nourishment. The studies that form the basis for permits under the Environmental Code and the Continental Shelf Act for beach nourishment cost 3 million SEK

(Swedish Portal for Climate Change Adaptation, 2020). This adaptive measure could provide other municipalities facing similar risks a method to reduce the risk.

4.5.3 Knowledge gaps and recommendations

Better knowledge of individual tipping points for coast aquifers along the Swedish coast would help determine the subsequent risk of saltwater intrusion. A methodology to calculate these tipping points of seawater intrusion can be found in Mazi et al. (2013). Studies should focus on coastal settlements on the south-eastern coastline where aquifers provide drinking water. These areas also commonly have aquifers in the sedimentary rock, which is more susceptible to saltwater intrusion. Investigations similar to Eriksson et al. (2018) can then be undertaken to quantify each specific site's risk. There is already good knowledge of which areas will flood and the infrastructure that is put at risk (Myndigheten för samhällsskydd och beredskap, 2018). However, more information on indirect consequences, such as the loss of habitats on local ecosystems, could be obtained in the future.

4.6 Health risks due to high temperatures

- **Increased risk of urban heat waves in summer**
- **Increased spread of diseases from vectors**
- **Higher water temperatures increase the risk of exposure to**

4.6.1 Current risks

4.6.1.1 Heat-related mortality

Heat-related mortality increases at high temperatures (Rocklöv and Forsberg, 2008). The risks are individual as they depend on the person's health and other factors. More vulnerable groups are older people and people with cardiovascular diseases (Folkhälsomyndigheten, 2015). However, both the duration and the intensity of heatwaves are linked to mortality in Sweden. The heat wave duration is the most critical factor for mortality in adults under 65, while the high temperatures are the most critical factor for people over 65 years old (Rocklöv et al., 2014). It is also likely that the geographical location is influential to the risk. For example, in California, it has been shown that sensitivity to heat is higher in the coastal regions than in the drier inland regions (McElroy et al., 2020). For Sweden's case, sensitivity to high temperatures may be higher in the North due to the population being less used to higher temperatures (Oudin Åström et al., 2020). Socioeconomic factors have also been linked to vulnerability to heat stress (Rohat et al., 2019).

SMHI issues warnings of heatwaves if the maximum temperature is above 30 °C three days in a row or more (SMHI, 2019). In 2018, the heatwave in Sweden had more days in July, with temperatures above 30 °C than what has ever been previously recorded. There were approximately 700 more deaths during the period June – August compared to the same period in other years, but the statistics do not show whether the deaths were caused by the heat (Folkhälsomyndigheten, 2018a).

4.6.1.2 Infectious diseases

The spread and range of several infectious diseases depend on the climatic conditions. However, it is difficult to determine whether increases or decreases in the spread of different diseases are related to climate change, especially as there may be other factors influencing the spread and distribution of diseases (Carlson et al., 2011).

The native species of tick in Sweden, a vector of both Tick-Borne Encephalitis (TBE) and Lyme borreliosis, has been increasing in numbers and distribution, and the spread of the diseases is also increasing (Carlson et al., 2011). Ticks are now found further north than thirty years ago, covering southern and central Sweden and the whole coastal area of Norrland (Jaenson et al., 2012b). There can be several reasons behind the increased distribution, partly due to increases in host animals' availability and to a milder climate with a longer warm season (Jaenson et al., 2012a). Host species of different parasites can also spread further due to climate change and thereby increase the parasite spread (Deksne et al., 2020).

In salt or brackish water, the bacteria in the Vibrio group (causing the illness Vibriosis) is present, and its growth is increased in water temperatures above 20 °C (Folkhälsomyndigheten, 2017b). During warm summers, there have been outbreaks of Vibriosis, where most of the infected persons are exposed to the bacteria when swimming in the Baltic Sea (Folkhälsomyndigheten, 2017b). The summer of 2014 was hot, and with more Vibriosis cases compared to average years in both Sweden and Finland (Baker-Austin et al., 2016). The disease is not contagious between humans (Folkhälsomyndigheten, 2017b), but water-borne diseases can also impact humans by infected drinking water. In 2010, an outbreak of the parasite Cryptosporidium affected the drinking water supply for the city of Östersund (Carlson et al., 2011). There were 27 000 people infected by the outbreak, with gastrointestinal illness and complications (Widerström et al., 2014). The cause of the contamination is not known (Folkhälsomyndigheten, 2016).

Tularaemia is a vector-borne illness transmitted by a range of different animals, including mosquitos and hares (Ma et al., 2020). The bacterium can also survive in water, so contaminated water contributes to some outbreaks (Lindhusen Lindhé et al., 2018). In the summer months of 2019, there was an outbreak of Tularaemia in central Sweden, with about four times the amount of cases compared to the average of the past two decades (Dryselius et al., 2019). In Sweden, most cases occur in the summer months (Lindhusen Lindhé et al., 2018), and rising temperatures in the future may lead to a long summer, leading to an increase in the number of cases. Tularemia outbreaks are local suggests that other factors influence its spread to a greater degree than large-scale temperature changes (Rydén et al., 2009). A recent modeling study indicated that hydroclimatic changes such as precipitation and runoff are more influential for the spread of Tularaemia. The study projected an increased spread of the Tularemia disease in the central and north of Sweden: more specifically, the counties of Norrbotten, Jämtland, north Gävleborg, Dalarna, and Värmland (Ma et al., 2020).

4.6.2 Risks in 2050 – 2070

4.6.2.1 Heat-related mortality

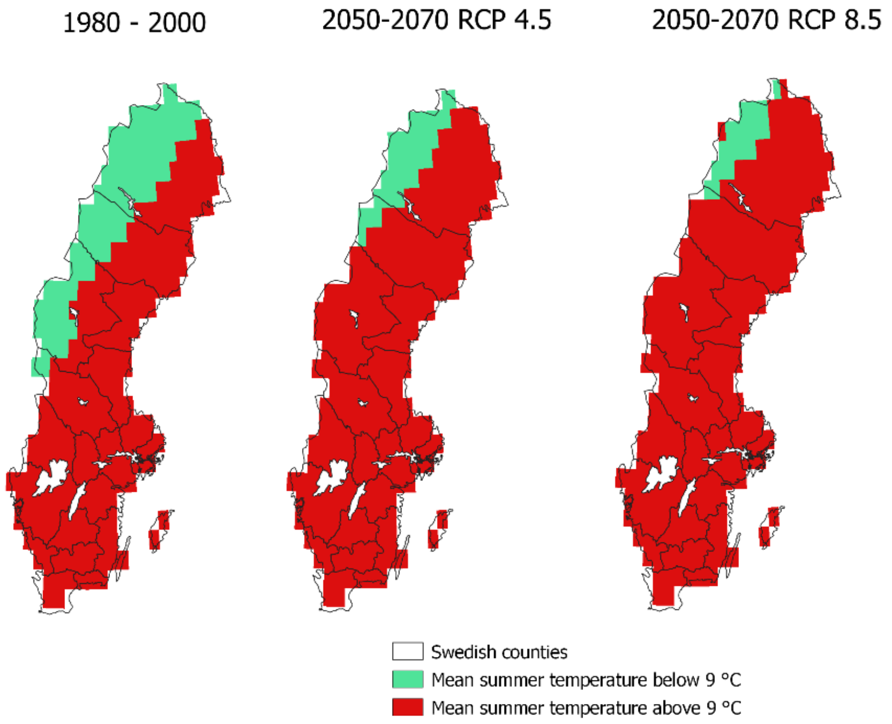
As the temperature in Sweden increases, mortality during heat waves is expected to increase, especially in the northern areas that are not used to higher temperatures (Rocklöv and Forsberg, 2008). The climate index of heat waves from SMHI is calculated as the highest number of consecutive days with mean daily temperatures over 20 °C (SMHI, 2020a). Using climate models, SMHI (2020a) found a dramatic increase in the index under the RCP 8.5 scenario towards the end of the century for all of Sweden. The projections for 2021-2050 are similar for RCP 4.5 and RCP 8.5 scenarios, but towards the end of the century, there are much more significant differences between the scenarios. The heatwave index will be the highest in south-eastern Sweden, especially around lake Mälaren and the eastern Baltic coast, including the Gotland and Öland islands, as well as the west coast of Skåne and around lake Vänern (SMHI, 2020a). The areas with high heat wave indices are thus likely to experience high temperatures for many consecutive days in the future. Most counties in Svealand and Götaland are aware of the risks of high heat to human health, especially in cities (e.g. Länsstyrelsen Blekinge län, 2014; Länsstyrelsen i Västra Götalands län, 2017; Länsstyrelsen Kalmar län and Lars Ljungström, 2012; Länsstyrelsen Skåne, 2020; Länsstyrelsen Stockholm, 2014; Länsstyrelsen Västmanlands län, 2013).

4.6.2.2 Infectious diseases

The spreading of diseases from vectors, such as ticks or mosquitos, is expected to increase. There are many species of potential vectors that are already in Sweden that can spread new diseases. The changing climate also allows new vector species to spread to Sweden from the south and expand the distribution of native vectors northward within the country as vector insects often benefit from warmer temperatures (Carlson et al., 2011; Garamszegi, 2011).

Many counties mention in their climate adaptation plans increasing risks to human health from both vector-borne diseases and pathogens in water resources (e.g. Länsstyrelsen i Kronobergs Län, 2016; Länsstyrelsen Jämtlands län, 2018; Länsstyrelsen Östergötland, 2014; Länsstyrelsen Västerbotten, 2014; Länsstyrelsen Västmanlands län, 2013). The Public Health Agency of Sweden published a report in 2011 (Carlson et al., 2011) describing the connections between climate and public health without making any predictions. In 2007, the Climate and Vulnerability Report (*Sverige inför klimatförändringarna - hot och möjligheter*, 2007) made a risk assessment of several diseases that could be connected to climate change. The diseases classified as high or very high risk were Borrelia, Visceral Leishmaniasis, and Vibriosis contracted from ticks, mosquitos, and lake water, respectively.

The common species of tick in Sweden (*Ixodes Ricinus*) thrive in humid areas near the ground surface (Jaenson et al., 2018). The number of days with temperatures above nine degrees is thought to correlate with the higher transmission of the TBE virus due to less tick activity at colder temperatures (Jaenson et al., 2018). Mean summer (June – August) temperatures are above 9 °C in most of Sweden, with the area increasing under both future scenarios RCP 4.5 and RCP 8.5. Although the location of temperatures above 9 °C during the reference period (figure 13) is further north than the actual spatial distribution of ticks in the same period, the actual distribution has expanded since then, especially in areas near lakes (Jaenson et al., 2012b). The northward migration of warmer summer temperatures shown in figure 20 reflects that suitability for ticks and the transmission of TBE may be expanding with climate change. This expansion is controlled by water availability and the ability of ticks to disperse in the landscape.


1980 - 2000

2050-2070 RCP 4.5

2050-2070 RCP 8.5

Figure 13*: Mean summer (June - August) temperature above or below nine degrees centigrade.*

There is an increasing risk of spreading water-borne diseases when water temperatures increase (Carlson et al., 2011). An increase in pathogens is most likely due to warmer waters for a more extended period, favorable for growth (Statens Veterinärmedicinska Anstalt et al., 2019). However, warm water temperatures can decrease the infection risks for enteric pathogens (e.g., E. coli) due to inactivation at higher temperatures (Coffey et al., 2014). Other less sensitive pathogens (e.g., Norovirus) can expand their distribution due to increased survival at higher temperatures (Sterk et al., 2013).

There can be many factors driving temperature change in lakes, but the most important are the air temperature and solar radiation (Schmid and Köster, 2016). The effect of air temperature warming on lake water temperature can be dampened or increased by the lake's morphology, stratification, and mixing regime. Warm temperatures early in the year can increase the stratification of a lake, which causes the surface layer to be smaller in volume and faster to warm up in the summer from higher temperatures (Piccolroaz et al., 2015). A larger volume of water takes longer to heat up, and there is more prominent inertia of temperature change in larger lakes than in smaller lakes, and the thickness of the surface layer (i.e., how stratified the lake is), as well as the total depth of the lake, affects the rate of temperature change (Toffolon et al., 2014). Hence, the air temperature change can be used as an indicator of surface water temperature change (Piccolroaz et al., 2020). The climate models predict summer air temperature increase in all of Sweden. The temperature change is more extensive in the RCP 8.5 than in the RCP 4.5 scenario. While summer temperatures are higher in the south, the temperature increase is higher in the north (figure 14).

Regarding pathogens in surface water, the projected air temperature increase suggests that northern Sweden may find an increased survival rate for many pathogens, while the changes for southern Sweden are not as drastic.

The Swedish water treatment infrastructure is adapted to treating the water from bacteria, but the threat to water quality from parasites and viruses will likely increase in the future (Svenskt Vatten, 2007). The current water treatment methods may then not be adapted to these new threats, as mentioned by the counties Blekinge (Länsstyrelsen Blekinge län, 2014), Jämtland (Länsstyrelsen Jämtlands län, 2018) and Västerbotten (Länsstyrelsen Västerbotten, 2014). There is a high risk of organic contaminants reaching the water supply when untreated water is released due to high flows (Svenskt Vatten, 2007).

4.6.3 Knowledge gaps

The indoor temperature is essential when considering the heat effects on health, especially because many people in Sweden spend most of their time indoors (Folkhälsomyndigheten, 2018b). Many factors influence the indoor temperature during a heatwave, such as air conditioning, the type of building, and location in the city (Folkhälsomyndigheten, 2018b). Folkhälsomyndigheten (2019) has developed a method for mapping the risk of high temperatures in urban areas based on building materials, vegetation, geometry and density of buildings, and population vulnerability. Trees and other vegetation are essential to reduce high temperatures in cities (Länsstyrelsen i Stockholms län, 2019). For example, some local studies have been made in Stockholm (Länsstyrelsen i Stockholms län, 2019; Lindberg et al., 2012), but to determine relative risks on a national scale, more cities need to conduct studies mapping heat-related health risks.

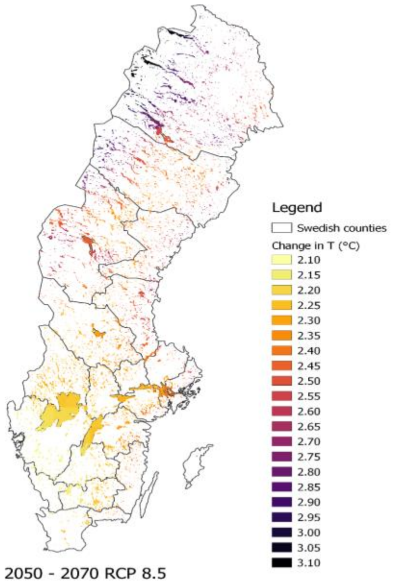


Figure 14: *Air temperature change under RCP 8.5 from climate models with resolution 0.5 degrees, masked by surface water coverage with resolution 1000 meters*

The National Veterinary Institute mentions a risk of increasing resistance to antibiotics with climate change (Statens Veterinärmedicinska Anstalt et al., 2019). They attribute this increase to the risk of sewage overflow and use of antibiotics as diseases spread. Higher antibiotic resistance may develop in microbes due to physiological changes caused by increasing temperature (Rodríguez-Verdugo et al., 2020). More research is needed to understand the link between climate change and antibiotic resistance (Rodríguez-Verdugo et al., 2020). The work to manage antibiotic resistance in Sweden is focused on using antibiotics and the communication around it, with no specific mention to climate change (Folkhälsomyndigheten, 2014).

4.7 Risks for terrestrial ecosystems

- **Changes in the climate cause migration of biomes, often to higher latitudes or altitudes. There is a risk of loss of species who cannot adapt to the change or migrate to suitable locations.**
- **An earlier start of the vegetation period may increase the frost damages to plants.**
- **The temperature around zero degrees can cause an ice layer to form on top of the snow, preventing mammals' grazing such as reindeer.**

4.7.1 Current risks

The tolerance of different species to temperature change, especially during their most vulnerable life stages, determines how a species will be affected by climate change (Loarie et al., 2009). A study in Skåne, Sweden, found that past changes in flora distribution could be attributed mainly to rising temperatures and land-use change (Tyler et al., 2018). The species distribution of pollinators in alpine areas in northern Sweden is changing, with southern species migrating upwards to the alpine areas and increasing the number of species in the high alpine areas (Franzén et al., 2012). The horizontal movement required to keep up with a specific temperature is more prominent in flat landscapes than in mountain regions due to the topography difference (Peterson, 2003). Therefore, the shift of habitats may be more significant in flat landscapes than in mountain regions (Loarie et al., 2009). However, for species adapted to live in a mountain region's highest altitudes, there may be no place to migrate to when the climate warms (Peterson, 2003), such as in many alpine ecosystems around the world (e.g., Cresso et al. 2020)

Climate change can affect different species differently, causing previously well-timed events to lose their timing, often referred to as phenological mismatch. Examples of this are roe deer’s birth advancing slower than the start of the growing season (Rehnus et al., 2020) or mountain hares fur becoming white earlier than the snow cover, making them more visible to predators (Hofmeester et al., 2020).

4.7.2 Risks in 2050 – 2070

Warmer temperatures have been found to increase the length of the growing period in northern ecosystems (Richardson et al., 2018; Schwartz et al., 2006). The length of daylight hours (photoperiod) does not inhibit an earlier start of the season (Richardson et al., 2018), although it may have a more restricting effect on low-latitude species (Zohner et al., 2016). The earlier vegetation period's start seems to make the vegetation more sensitive to cold temperatures and frost damages (Richardson et al., 2018). There are also indications that some plants' species will be delayed at the start of the vegetation period if there is a lack of a chilling period during winter (Laube et al., 2014). Frost damage to spruce seedlings is projected to increase in southern Sweden as the bud burst will occur earlier in the season in the period 2036-2065 compared to 1961-1990, but in northern Sweden, this risk is not expected to increase (Langvall, 2011).

At temperatures above zero, snow melts. When the temperature goes below zero, the water freezes again, which creates a layer of ice on the snow, preventing reindeers from grazing. The situation creates a need for support feeding, which increases the risks of spreading diseases between the animals as the animals get close to each other (Sametinget, 2017).

The potential habitats for arctic and subarctic mammals have been shown to increase to 2080 for many species (Hof et al., 2012). However, the animals' ability to disperse to new areas and human interaction: for example, hunting and land-use changes, limits the ability of arctic animals to find new habitats (Hof et al., 2012). As the climatic zones move northward, species can either adapt genetically through generations to the new conditions or migrate to new suitable environments (Bernes, 2016). The fundamental niche refers to the ranges of environmental parameters that a particular species could exist within if there were no competition from other species. The ranges of parameters of the fundamental niche are thought to be constant. The niche a species occupies in an ecosystem is narrower than the fundamental niche and is determined by competition and interaction with the other species. Changes in the environment can cause species to occupy a slightly different niche than the previous one. However, the niche of a species will not shift outside of the fundamental niche (Wasof et al., 2013). Species may therefore show adaptive capacity up to a certain threshold. Climate warming can be too fast for many species to adapt or migrate, mainly due to the fragmentation of habitats from human land use (Bernes, 2016). The tree line in the Swedish mountains can advance by several hundred meters to the end of the century, and with a 3-4 degrees warming, most of the bare mountain areas in Sweden would be lost (Bernes, 2016). Sensitive species in alpine areas are likely to be lost when there is no place to migrate (Bernes, 2016).

4.7.2.1 Analysis of hydroclimatic change to understand the change in conditions for Swedish ecosystems

Both terrestrial and aquatic ecosystems depend on freshwater to thrive, and fresh water on the surface is dependent on water availability from the atmosphere in the form of precipitation and energy in the form of radiation. Understanding how water and energy availability will change in the future enables an insight into how ecosystems may react to these ongoing hydroclimatic changes. The Budyko framework is an essential tool that can be used for such a purpose (Budyko 1974). The framework provides a relationship between the aridity index (PET/P) and the evaporative ratio (E/P). The first represents the location's level of aridity, whereas the second shows how much of the water falling as precipitation partitions into evaporation. Its inverse then provides information on the quantity of water that is usually running on the surface and available to ecosystems and aquatic resources. It is common to refer to the mathematical space generated by PET/P on the x-axis and ET/P on the y-axis as the Budyko space. Looking at the ratios between the vital water and energy balance parameters can give a general insight into the primary wetting and drying trends (Greve et al., 2014), linking changes in energy demand driven by climate warming to effects on water partitioning and water availability on land (Piemontese et al.). This approach has been used to understand hydroclimatic changes in Sweden from the mid-20th century to the beginning of the 21st century (van der Velde et al. 2014). We here make a similar approach between the reference period 1980 – 2000 and over the future period 2050 – 2070 by using the CORDEX outputs of precipitation (P), evapotranspiration (ET), and potential evapotranspiration (PET). As PET and P's ratio is the dryness index, values over 1 indicate that the system is water-limited, meaning that the temperature is high enough to evaporate more water than is available. The ET is calculated from the water balance (i.e., P-R), while the PET is calculated from modeled and observed annual temperature with the Langbein formula. All points from the analysis in Sweden have a dryness index below 1, indicating an energy limited system where more of the available water could be evaporated if the temperatures were higher. The ratio of ET and P is the evaporative index, indicating how much of the incoming precipitation is evaporated, and is defined between 0 and 1 (figure 15a).

The magnitude (dimensionless) (figure 15a) and direction (in degrees) (figure 15b) of the change between the observed data in the reference period and the modeled data in the future period with scenario RCP 8.5 is plotted in the Budyko space and on the map of Sweden (figure 16a and b, respectively) following the calculations by Jaramillo et al. (2018) for Sweden. The most significant change is projected for northern Sweden, except in the mountain areas along the border to Norway. The change in hydroclimatic conditions is most pronounced in the far north and decreases to the south. A more significant change is also projected for the Mälardalen area, south-eastern Sweden, and large lakes. The magnitude of change can be interpreted as the sensitivity of an ecosystem to climate change (van der Velde et al., 2014). The vegetation can adapt to temperature and precipitation changes, which would not alter the position in the Budyko space much. The difference of magnitude in geographical space can indicate the difference in sensitivity between different ecosystems. However, the raster's coarse resolution makes it difficult to distinguish between different ecosystems, especially in heterogeneous landscapes such as mountain regions. The raster values represent averages over 50 km cells and thus can represent a multitude of different ecosystems making interpretation difficult.

Topography influences the spatial variability of climate, creating cooler and warmer parts of the landscape at different altitudes and aspects. Species at the edge of their optimum temperature range in a particular environment can find refuge where regional climate changes are buffered (Ackerly et al., 2020). Microclimates can sometimes act as refugia against climate change. The variability of climate on a local scale is lost by the coarse resolution of the climate models. To better understand climate warming's effect on biodiversity, a higher resolution analysis is needed, which takes microclimates into account (Lenoir et al., 2017).

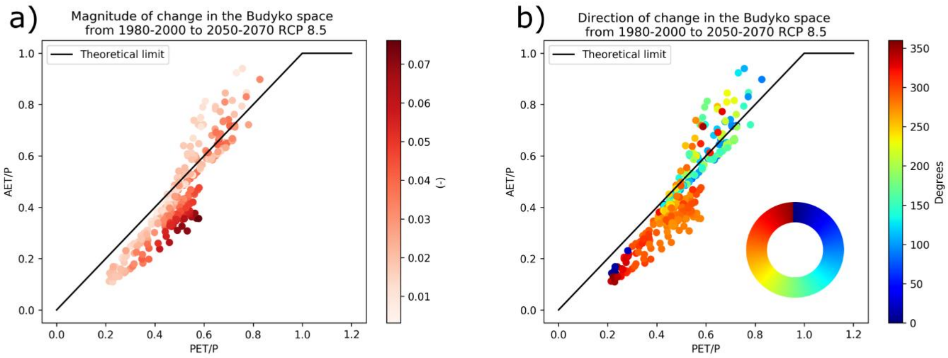


Figure 15: *Every cell in Sweden from the climate model of 2050-2070 in scenario RCP 8.5 plotted in the Budyko space. The color of the points shows a) magnitude of change from 1980-2000 to 2050-2070 and b) the direction of change from 1980-2000 to 2050-2070 in degrees.*

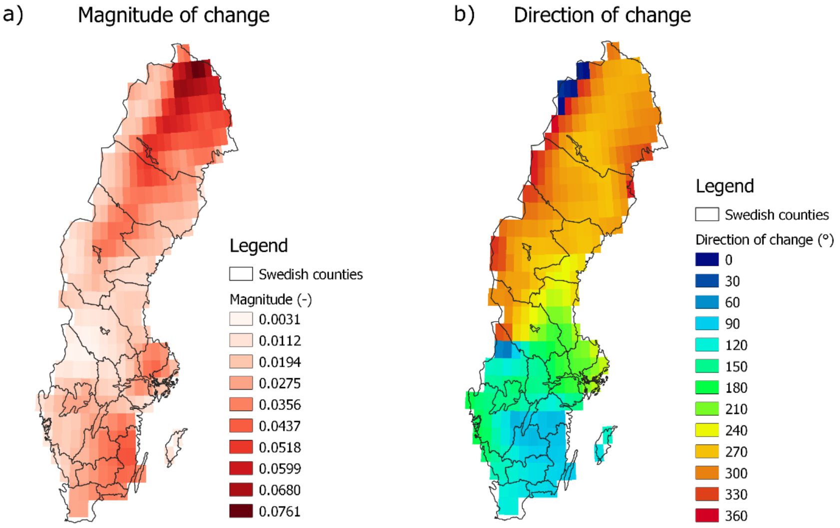


Figure 16: a) magnitude of change from 1980-2000 to 2050-2070 and b) the direction of change from 1980-2000 to 2050-2070 in degrees.

The direction of change in the Budyko plot describes the change between the reference period and the future period under RCP 8.5. The plot's change is to the left for most of northern Sweden, indicating a lower dryness index in the future period. In Mälardalen and along the west coast, the movement is towards a lower evaporative index. South-eastern Sweden has a movement towards higher dryness index and, in some places, also a higher evaporative index. The movement suggests that while northern Sweden could become wetter in the future period with a higher P than of PET, southern Sweden may become drier with a lower increase of P than PET.

Most of the Budyko plot points with high evaporative index fall outside the theoretical limits, with higher ET values than PET, evidencing some uncertainty of the climatic projections and models used for the calculations of hydrological variables. There is also a greater spread of those points and no clear pattern of either magnitude or direction. A more precise analysis is needed with higher geographical resolution and more reliable calculations of evapotranspiration. These results indicate that future hydrological changes will be most pronounced in northern Sweden, which can have significant impacts on ecosystems. The results also indicate that temperature rise in south-eastern Sweden will increase the evaporative capacity more than the precipitation increases, which needs to be given more attention concerning the risk of agricultural drought.

Knowledge and Recommendations

We recommend a holistic approach to understand hydroclimatic changes over the three most important biomes in Sweden; tundra, boreal and temperate forests. Most studies of the impacts of climate change on ecosystems are carried at the plot scale in Sweden, and they mainly focus on climatization and adaptation of species to temperature changes or increasing carbon dioxide concentrations. There is a lack of studies regarding the adaptation and resilience of these ecosystems to precipitation and other important climatic parameters such as wind velocity, atmospheric moisture, potential evaporation. Even more, these changes will develop at a more regional and landscape scale.

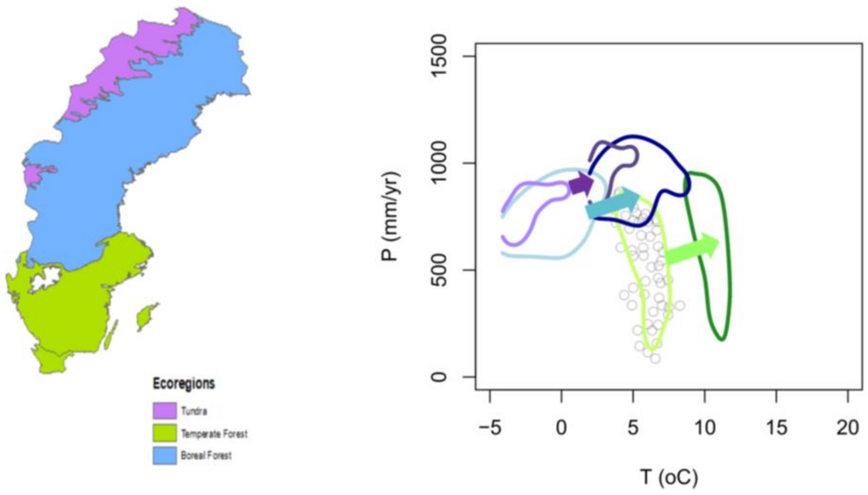


Figure 17: *Changes in the tundra, temperate and boreal forest biomes in Sweden in terms of mean temperature and total annual precipitation. The arrows visualize the changes from current conditions to future conditions. Notice that the new polygons do not intersect in most cases with the polygons describing these biomes' original conditions.*

Climate change will generate new conditions that these three biomes have not experienced before, at least in Sweden. It is necessary to understand these conditions in the light of hydroclimatic frameworks such as the Budyko framework here described (Bdyko 1974; Piemontese et al., 2020; Jaramillo and Destouni, 2014) or the Novel Climate framework (Williams et al. 2007; Williams and Jackson 2007; Dahinden et al. 2017). These frameworks help understand risks at a more landscape scale rather than a species- or individual-dependent approach. A simple plot of how changes in precipitation and temperature in each of these three ecosystems occurs can show that, indeed, most of the areas of these ecosystems will experience combinations that do not currently exist at those locations. Hence, risks do exist regarding how these terrestrial ecosystems react to these novel climates that should be studied soon.

4.8 Risks in aquatic and marine ecosystems

- **Climate change can cause a migration of biomes, which is a risk to the survival of many aquatic species. A warmer climate may also increase the suitability of invasive species, which can threaten the existing ecosystems.**
- **Increasing runoff and precipitation may decrease the salinity of the Baltic Sea, negatively impacting saltwater species.**
- **Increasing runoff could increase the transport of nutrients from land to the Baltic Sea and to freshwater lakes, enhancing eutrophication problems.**

4.8.1 Current risks

Eutrophication and hypoxia in the Baltic Sea are linked primarily to nutrients discharging to the ocean from rivers and atmospheric deposition (Meier et al., 2019). For many decades, nutrients have been released from inland sources such as agricultural fertilizers, manure, and sewage water, through the river networks, and into the Baltic Sea (Arneborg and Gustafsson, 2020). Both nitrogen and phosphorus transport to the ocean varies significantly between years, with the variance mainly depending on runoff (Havs- och vattenmyndigheten, 2020d, 2020e). Direct effects of climate change have a lesser impact on nutrient loads than anthropological changes (Pihlainen et al., 2020). The life cycle of phosphorus in the ocean is about 50 years, while nitrogen can be converted between different forms by cyanobacteria and has a residence time of only a few years (Arneborg and Gustafsson, 2020). With higher amounts of nutrients in the water, the organic material in the ocean increases. The decomposition of organic material requires oxygen, and as the algae sink to the bottom of the ocean, the water is depleted of oxygen.

Climate-induced changes in precipitation patterns and temperature can affect eutrophication even in lakes with limited human interaction (Lu et al., 2019). Excessive nutrient transport to lakes can influence the water quality, for example, by increasing the severity of algal blooms and increasing oxygen depletion (Couture et al., 2014). There has been no significant change in total phosphorus concentration in Swedish lakes and rivers over the past twenty years (Havs- och vattenmyndigheten, 2020a).

The majority of lakes and rivers that are relatively unaffected by human activities have a high or good status regarding eutrophication (Havs- och vattenmyndigheten, 2020a). The phosphorus concentration is primarily used when determining eutrophication status in freshwater (Havs- och vattenmyndigheten, 2020b). The nitrogen levels in Swedish lakes and rivers are generally low in northern Sweden. There are low or moderate nitrogen concentrations in most lakes and rivers not influenced by human activities (Havs- och vattenmyndigheten, 2020b). The regions with severe eutrophication problems in freshwater are southern Scania, Mälardalen, Östergötland and southern lake Vänern (Havs- och vattenmyndigheten, 2020c). For Lake Mälaren, the ecological status in terms of phosphorus and nitrogen concentrations is unsatisfactory in most inflows, although the status at the outflows to the Baltic sea is good (Sonesten et al., 2013). The transport of phosphorus to Mälaren decreased dramatically in the 1960s due to improved water treatment but has remained stable since then (Sonesten et al., 2013). The primary source of phosphorus to Mälaren is from agricultural land, but there is also a contribution from private sewage, treated water, surface runoff, and leaching from forestry (Sonesten et al., 2013).

Algal blooms can occur both in the ocean water and in lakes. The probability of algal blooms is highest during summer and autumn. Algae need phosphorus and nitrogen for their growth, and eutrophication is a cause of more intense algal blooms. Health risks for people swimming in the water during algal blooms exist because some species of algae and cyanobacteria produce toxins (Havs- och vattenmyndigheten, 2019). The growth of algae and cyanobacteria also contributes to low oxygen levels near the ocean floor, as the decomposition of organic material uses up oxygen (Klimatanpassning.se, 2019).

Deepwater is normally reoxygenated by vertical mixing with oxygen-rich surface water. Increased precipitation and increased runoff from land due to climate change will increase the addition of fresh water to the surface water, which will increase the stratification by increasing the density difference between surface and deep water. Vertical mixing of the water column can thus be prevented due to the water column's increased stratification. When the oxygen is depleted from the deep water, the water can become anoxic, with severe marine life consequences. The toxic substance hydrogen sulfide is formed in anoxic water (Hansson et al., 2018).

Climate warming may also increase the water temperature, which can lead to increased biological activity. The process of decomposing by increasing amounts of organic material increases oxygen consumption in the ocean, further depleting the deeper water of oxygen (Hansson et al., 2018). A large area of the Baltic Sea has anoxic conditions, and the area has been increasing for some years now. There are anoxic conditions in the sea between Gotland and the mainland of Sweden (Hansson et al., 2018). In lake Mälaren, there is a lack of oxygen in the most eutrophicated areas, which is more severe during warm summers (Sonesten et al., 2013). During warm summers, the water's surface layers warm and prevent mixing in the water column, restricting the bottom layers from being oxygenated.

The total effects of warming waters on aquatic life can be challenging to establish due to complex food web systems, where one species' effect may affect other species (Jonsson and Setzer, 2015). The water temperature in lake Vättern has been increasing since 1980, which has direct and indirect effects on the lake species (Jonsson and Setzer, 2015). Warmer winter temperature advances the development of the Arctic charr's fry and its prey zooplankton, but the change is more rapid for the fry, and thus the two events become desynchronized. Similarly, the fish species vendace is affected by climate warming, which affects the food supply for the juvenile Arctic charr (Jonsson and Setzer, 2015). There are differences between different lakes and different species in how climate affects fish recruitment (Sandström et al., 2014). For example, the fish species Smelt is disadvantaged by water temperatures above 20 °C, and if summer temperatures in a lake are high for several consecutive years, the species may not have a chance to survive (Keskinen et al., 2012). Climate warming is expected to increase the suitability of many new species (Naturvårdsverket, 2020a). In the past (1979-2018), the climate change velocity in inland standing waters had a global mean of 14 km/decade (Woolway and Maberly, 2020). In Sweden, the rate was highest in the southeastern part, including lakes Mälaren and Vättern, but also around lake Storsjön in Jämtland.

The introduction of new species to an ecosystem can have a significant impact, for example, by increased competition between species or increased predation. The EU has classified 66 invasive alien species, some already in Sweden and some possibly arriving in the future. Disruptions to ecosystems can have economic consequences in terms of, for example, fisheries. Human activities most often introduce new species, and new species mainly reach marine ecosystems in Europe via shipping, for example, in the ballast water (Katsanevakis et al., 2013; Nunes et al., 2014). The number of invasive species that have been introduced to European waters from shipping has been increasing for several decades (Katsanevakis et al., 2013).

Swedish lakes have so far been affected by few invasive species (Nellbring et al., 2011). Monitoring systems for invasive alien species in freshwater systems are being developed (Naturvårdsverket, 2020b). An essential part of monitoring includes citizen reporting of alien species' observations (Havs- och vattenmyndigheten, 2017). In lake Mälaren, the native species of crayfish have been lost due to the introduction of the crayfish's plague and replaced by a different species of crayfish in the ecosystem (Sonesten et al., 2013). Other already established alien species include Canadian waterweed (*Elodea canadensis*), Zebra mussel (*Dreissena polymorpha*), and *Nymphoides peltate* (Nellbring et al., 2011). There is a lack of information on the risks of specific new species, especially as an alien species can exist in small populations for a long time before suddenly becoming invasive (Nellbring et al., 2011).

4.8.2 Risks in 2050 – 2070

Climate models project higher precipitation and runoff in the future, which will increase the freshwater inflow to the Baltic Sea. Saltwater is denser than fresh water and will sink to the ocean's lower levels, allowing the deep water to move up and be oxygenized closer to the atmosphere. A possible future decrease in the Baltic salinity could decrease the exchange between deep and surface water, which prevents oxygenation of the deep water (Arneborg and Gustafsson, 2020) and further increases anoxia episodes in the sea. Higher runoff may also increase the transport of nutrients from land, contributing to eutrophication. Higher water temperatures can speed up organic processes, increasing the amount of organic material which uses up oxygen as it decomposes (Arneborg and Gustafsson, 2020). Decreasing the Baltic Sea salinity is believed to negatively impact saltwater species, including the vital species of cod and blue mussel (Bernes, 2016).

Nitrogen leaching is highly related to runoff, which is projected to increase with climate change, especially during the autumn season and the leaching of nitrogen (Øygarden et al., 2014). The highest losses of nitrogen from arable land occur in south-western Sweden, where the precipitation is high, while the loss of phosphorus is more spatially variably related to the soil type (Kyllmar et al., 2014). However, higher precipitation induces higher phosphorus loads (Couture et al., 2014). In addition to changes in hydroclimatic variables, changes in agricultural practices and policies also significantly influence the total leaching of nutrients to water bodies (Couture et al., 2014). For instance, reductions of nutrient load to the Baltic Sea can compensate for the adverse effects of climate change, improving the Sea's ecological status and decreasing eutrophication (Saraiva et al., 2019). Future reductions in nutrient loads need to be determined considering the increased transport of nitrates due to higher winter streamflow (Teutschbein et al., 2017). In a future scenario with business as usual, both regarding climate and nutrient emissions, the Baltic Sea is predicted to suffer decreasing biodiversity and loss of habitats (Bauer et al., 2019). Depletion of oxygen is expected to increase in saline water, which deteriorates the available habitat for saltwater species (Wåhlström et al., 2020).

The IPCC report (Sari Kovats et al., 2014) states that there is low confidence that higher temperatures will increase the severity of algal blooms, although warmer temperatures can increase the season's length by allowing plankton to start growing earlier (Weyhenmeyer, 2001). Higher annual precipitation can lead to lower Baltic Sea salinity, which is favorable for cyanobacteria (Klimatanpassning.se, 2019). Future increases in algal blooms due to warmer water temperatures threaten the water quality of Swedish lakes, for example, the lake Vänern, which currently has good water quality (Eklund et al., 2018).

Rising temperatures are expected to shift the climate zones, impacting the different biomes and requiring adaptation or migration of the biomes' species. The survival of aquatic species is dependent on both their inherent mobility and the ability to travel between suitable habitats, which is impacted by how fragmented the different habitats are. For example, the movement upstream in rivers can be hindered by dams. Fish spawning in the rivers and channels around lake Vättern may be inhibited by low water levels in the future (Eklund et al., 2018). In the future period of 2006 – 2099, the velocity of climate change in freshwater lakes is expected to increase globally to 57.0±17.0 km/decade for the RCP 8.5 scenario and higher in summer than in winter (Woolway and Maberly, 2020).

Reduction of water availability could occur during low flow periods (often summer) (Eklund et al., 2018). For instance, the number of days with shallow water levels in lake Vänern for transport to pass fully loaded are expected to increase with a few extra days per year to the end of the century, a few more with RCP 8.5 than with RCP 4.5 (Eklund et al., 2018). Low water levels in Göta Älv (downstream of Vänern) may be caused by the low flow from the hydroelectric dam.

Another potential risk of climate change in the Baltic Sea may be the acidification of its waters. Increasing CO_2-levels in the atmosphere leads to increased CO_2-uptake in the oceans and is the most controlling pH factor in the Baltic Sea (Gustafsson and Gustafsson, 2020; Omstedt et al., 2012). The Baltic Sea's acidification is projected to continue, despite a buffering effect of increasing nutrient transport from land activities (Omstedt et al., 2014, 2012). Alkalinity from river transport and ocean processes counteracts a fraction of the effect from CO_2 (Müller et al., 2016). However, ocean acidification combined with ocean warming is a potential threat to cod fisheries in the Baltic Sea (Voss et al., 2019). While it is generally agreed that the Baltic Sea acidification will continue, there are uncertainties in how much of the effect will be counteracted by other processes and the response of the marine ecosystems.

5 Risk map for slow-onset risks in Sweden

Based on the eight slow onset risks described in Section 4, we have developed two different risk maps for Sweden in 2050 for both RCP4.5 and RCP8.5 scenarios.

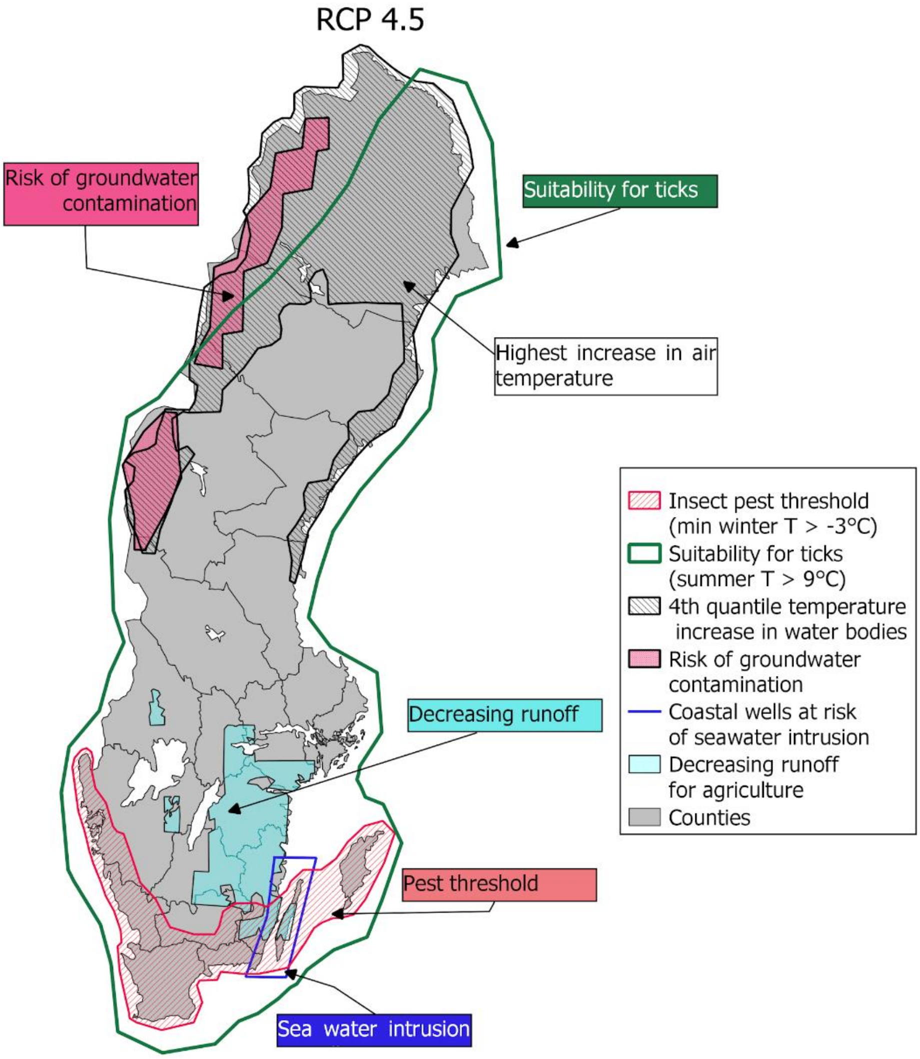


Figure 17: *Overview of a selection of climate-related risks in 2050-2070 under the climate scenario RCP4.5*

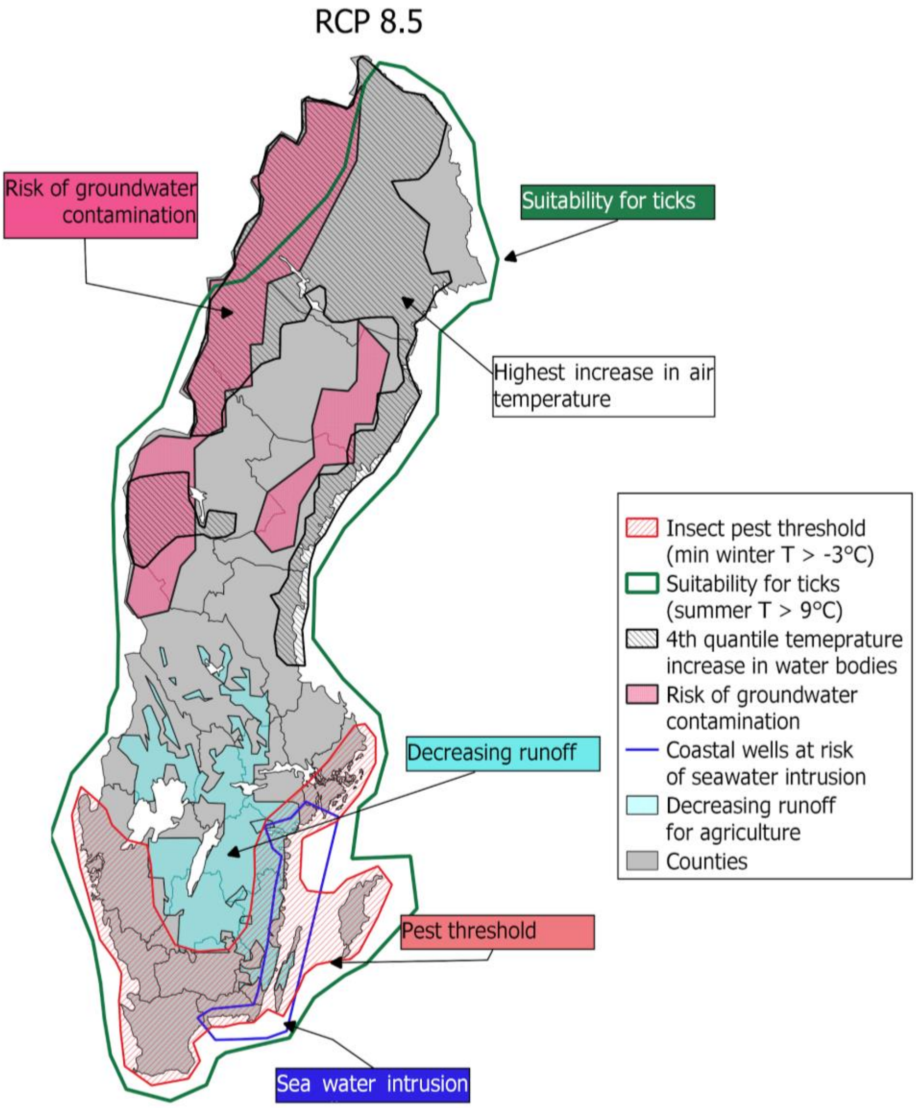


Figure 18: *Overview of a selection of climate-related risks in 2050-2070 under the climate scenario RCP8.5*

Conclusions

Different mitigation efforts are already taking place in Sweden, with many others planned to be introduced or expanded. Mitigation measures that are likely to impact the natural environment, in positive or negative ways, are wetland restoration, increased biomass cultivation for biofuels, and increased renewable energy production.

While there are numerous examples of climate adaptation in many sectors and levels of society, there is a need to develop further knowledge and cooperation of adaptation and harmonization on a national level. Adaptation requires determining which possible future to prepare for and often choosing an emission scenario for future projections. Different organs may choose to refer to different future scenarios, reflecting their different responsibilities and perspectives. It does, however, mean that the adaptive measures in the society depend on who makes the decisions.

The most significant consequences of climate change on groundwater supply are expected in southern Sweden. The country's southeastern parts are expected to have low groundwater levels, which affects water supply during summer and early autumn when groundwater levels are already at their lowest. We expect effects on both public and private water supply as groundwater abstraction may decrease as groundwater levels lower.

Groundwater levels over winter will increase in Sweden in the future. However, warmer summers with higher evaporation, combined with less recharge and more considerable strain on groundwater resources, will decrease groundwater levels, which means more significant seasonal variations and increased groundwater levels fluctuation. Northern areas are most at risk from groundwater contamination by purely groundwater fluctuations, with drinking water wells risking contamination if pollutants are in the vicinity. Areas with a significant increase in both precipitation and runoff are deemed high risk for contamination. The areas where there are high runoff and high precipitation changes are along the Norwegian border and an area 70 km inland of Sweden's north-eastern coast. These are areas where the conditions are most favorable to groundwater contamination, and it is necessary to make into possible contamination sources within these areas.

Climate effects on agriculture are not well known, and there are both positive and negative effects. Southeastern Sweden is most at risk of droughts, though there is conflicting information. Droughts can significantly impact water availability, energy and water consumption for irrigation, and crop yields, especially in areas where crops with groundwater irrigation. If there is a lack of water for irrigation, there is a risk of severe yield losses. Not only will less water be available for irrigation, but there will be less water in the soils, increasing the strain on crops. The areas highlighted here are areas that adaptive measures should be considered, such as planting new crops that require less water and changing agricultural practices. An example mentioned here is the increased cultivation of quinoa.

It is relevant to further the knowledge of the effect that a changing climate may have on different species regarding pests. While southern Sweden is most at risk of new pests, northern Swedish agriculture and forestry are at risk of more southern species spreading north. There is a risk of more use of pesticides for these reasons. Compared to uncultivated land, agricultural land releases rainwater at a faster rate, leading to increased leaching and the potential for flooding. Regarding leaching, the importance of the choice of crop, soils, fertilization, and tilling measures should be studied based on anticipated changes in the climate, including the climate's variability.

Projected future sea-level rise will inundate coastal regions, where most settlements and infrastructure are found. The intrusion of seawater into freshwater aquifers is usually limited to a zone approximately 100 m wide along the coastline. However, where the rock types are sedimentary, for example, in southern Sweden and the islands of Öland and Gotland, seawater intrusion can occur in aquifers further from the coast. Most risk areas are located in southern Sweden, allowing adaptation measures to be prioritized in these areas. There is also a risk for residential properties built along the coast. Waterside housing is sought after, and an increasingly large proportion of construction in southern Sweden, almost half, is located within the coastal zone (5 km from the coast). Sea level rise will result in direct costs to society, which will be exaggerated around densely populated areas where the loss and damage to property could be extensive. For example, in the long term, Öland could suffer from the decrease in tourism as touristic areas are lost to sea-level rise. Better knowledge of individual tipping points for coast aquifers along the Swedish coast would help determine the subsequent risk of saltwater intrusion. Studies should be focused on coastal settlements on the southeast coastline where aquifers provide drinking water as these are areas most at risk.

There are also health risks associated with climate change. Heatwaves in cities can induce increased mortality in vulnerable groups. There is a need for continued efforts to reduce the risks and increase preparedness, as extreme temperatures are likely to be more common in the future. This is especially important regarding the aging population, which may increase the vulnerability to heat-related diseases. There is considerable spatial variability in urban heat waves depending on many factors, which means that to determine risks at the national scale, more cities need to conduct studies mapping heat-related health risks.

The changing climate also allows new vector species that may spread new diseases to spread to Sweden from the south and expand the distribution of native vectors northward in Sweden. More drastic changes in land use can often outweigh the environmental response to slow-onset climate risks. There are still many impacts that climate change can have on ecosystems, and it is important to continue researching the potential long-term effects on ecosystems. While the future absolute temperatures are likely to be highest in southern Sweden, the temperature increase is higher in northern Sweden. This increased temperature will shift the biomes and require species to adapt or migrate. Rapid climate changes, coupled with anthropological influences, may however, cause a significant risk to biodiversity.

References

Aastrup M, Thunholm B, Sundén G. 2012. Klimatets påverkan på koncentrationer:34.

Ackerly, D.D., Kling, M.M., Clark, M.L., Papper, P., Oldfather, M.F., Flint, A.L., Flint, L.E., 2020. Topoclimates, refugia, and biotic responses to climate change. Frontiers in Ecology and the Environment 18, 288–297. doi.org/10.1002/fee.2204

Alcamo J, Döl P, Henrichs T, Kaspar F, Lehner B, Rösch T, Siebert S. 2003. Global estimates of water withdrawals and availability under current and future “business-as-usual” conditions. Hydrological Sciences Journal 48:339–348. doi:10.1623/hysj.48.3.339.45278. Publisher: Taylor & Francis eprint: https://doi.org/10.1623/hysj.48.3.339.45278

Andersson I, Jarsjö J, Petersson M. 2014. Saving the Baltic Sea, the Inland Waters of Its Drainage Basin, or Both? Spatial Perspectives on Reducing P-Loads in Eastern Sweden. AMBIO 43:914–925, doi:10.1007/s13280-014-0523-x

Andersson, E., Keskitalo, E.C.H., 2018. Adaptation to climate change? Why business-as-usual remains the logical choice in Swedish forestry. Global Environmental Change 48, 76–85. https://doi.org/10.1016/j.gloenvcha.2017.11.004

Andréasson J, Bergström S, Carlsson B, Graham LP, Lindström G. 2004. Hydrological Change – Climate Change Impact Simulations for Sweden. AMBIO: A Journal of the Human Environment 33:228–234. doi:10.1579/0044-7447-33.4.228. Publisher: Royal Swedish Academy of Sciences

Arheimer B, Donnelly C, Strömqvist J. 2013. Large-scale effects of climate change on water resources in Sweden and Europe :8

Arneborg, L., Gustafsson, B., 2020. Framtidens Östersjön – påverkan av övergödning och klimatförändringar (No. 2/2020). Stockholms universitets Östersjöcentrum & SMHI.
Augustsson A, Filipsson M, Öberg T, Bergbäck B. 2011. Climate change — An uncertainty factor in risk analysis of contaminated land. Science of The Total Environment 409:4693–4700. doi:10.1016/j.scitotenv. 2011.07.051

Baker-Austin, C., Trinanes, J., Salmenlinna, S., Löfdahl, M., Siitonen, A., Taylor, N.G.H., Martinez-Urtaza, J., 2016. Heat Wave–Associated Vibriosis, Sweden and Finland, 2014. Emerging Infectious Diseases 22, 1216–1220. https://doi.org/10.3201/eid2207.151996

Barth E, Herrmann R, Dahling T, Brenner R, Wright S, Clark P. 2009. Evaluation of airborne endotoxin concentrations associated with management of a crop grown on applied biosolids. Journal of Residuals Science and Technology 6:61–66

Bauer, B., Gustafsson, B.G., Hyytiäinen, K., Meier, H.E.M., Müller-Karulis, B., Saraiva, S., Tomczak, M.T., 2019. Food web and fisheries in the future Baltic Sea. Ambio 48, 1337–1349. https://doi.org/10.1007/s13280-019-01229-3

Beillouin, D., Schauberger, B., Bastos, A., Ciais, P., Makowski, D., 2020. Impact of extreme weather conditions on European crop production in 2018. Phil. Trans. R. Soc. B 375, 20190510. https://doi.org/10.1098/rstb.2019.0510

Bendz, A., Boholm, Å., 2019. Drinking water risk management: local government collaboration in West Sweden. Journal of Risk Research 22, 674–691. https://doi.org/10.1080/13669877.2018.1485168

Berhanu KG, Hatiye SD. 2020. Identification of Groundwater Potential Zones Using Proxy Data: Case study of Megech Watershed, Ethiopia. Journal of Hydrology: Regional Studies 28:100676. doi:10.1016/j.ejrh.2020.100676

Bernes, C., 2016. En varmare värld - Växthuseffekten och klimatets förändringar. Naturvårdsverket

Black-Samuelsson, S., Eriksson, H., Henning, D., Janse, G., Kaneryd, L., Lundborg, A., Niemi Hjulfors, L., 2017. Bioenergi på rätt sätt - om hållbar bioenergi i Sverige och andra länder (No. 10), Report by Skogsstyrelsen, Energimyndigheten, Jordbruksverket & Naturvårdsverket. Skogsstyrelsen

Bloomfield JP, Marchant BP. 2013. Analysis of groundwater drought building on the standardised precipitation index approach. Hydrology and Earth System Sciences 17:4769–4787. doi:10.5194/hess-17-4769-2013

Bloomfield JP, Williams RJ, Gooddy DC, Cape JN, Guha P. 2006. Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—a UK perspective. Science of The Total Environment 369:163–177. doi: 10.1016/j.scitotenv.2006.05.019

Boken, V.K., Cracknell, A.P., Heathcote, R.L., Heathcote, R.L., 2005. Monitoring and Predicting Agricultural Drought: A Global Study. Oxford University Press, Incorporated, Boulder, UNITED STATES

Boverket. 2009. Building for a Changing Climate. Boverket Https://www.boverket.se/en/start/publications/publications/2009/building-for-a-changing-climate/

Brecka, A.F.J., Shahi, C., Chen, H.Y.H., 2018. Climate change impacts on boreal forest timber supply. Forest Policy and Economics 92, 11–21. https://doi.org/10.1016/j.forpol.2018.03.010

Budyko. 1974. Climate and life. Academic Press.

Campana PE, Zhang J, Yao T, Andersson S, Landelius T, Melton F, Yan J. 2018. Managing agricultural drought in Sweden using a novel spatially-explicit model from the perspective of water-food-energy nexus. Journal of Cleaner Production 197:1382–1393. doi:10.1016/j.jclepro.2018.06.096

Carlson, J., Holm, L.-E., Engvall, A., 2011. Smittsamma sjukdomar i ett förändrat klimat. 2011-4-1 50

Changing Inputs of Terrestrial Dissolved Organic Matter to Lakes: Current Knowledge and Future Challenges. Ecosystems 18:376–389. doi:10.1007/s10021-015-9848-y

Civantos, E., Thuiller, W., Maiorano, L., Guisan, A., Araújo, M.B., 2012. Potential Impacts of Climate Change on Ecosystem Services in Europe: The Case of Pest Control by Vertebrates. BioScience 62, 658–666. https://doi.org/10.1525/bio.2012.62.7.8

Coffey, R., Benham, B., Krometis, L.-A., Wolfe, M.L., Cummins, E., 2014. Assessing the Effects of Climate Change on Waterborne Microorganisms: Implications for EU and U.S. Water Policy. Human and Ecological Risk Assessment: An International Journal 20, 724–742. https://doi.org/10.1080/10807039.2013.802583

Colombani N, Dinelli E, Mastrocicco M. 2016. Trend of Heavy Metal Release According to Forecasted Climate Change in the Po Delta. Environmental Processes 3:553–567. doi:10.1007/s40710-016-0146-2

Couture, R.-M., Tominaga, K., Starrfelt, J., Moe, S.J., Kaste, óyvind, Wright, R.F., 2014. Modelling phosphorus loading and algal blooms in a Nordic agricultural catchment-lake system under changing land-use and climate. Environmental Science: Processes & Impacts 16, 1588–1599. https://doi.org/10.1039/c3em00630a

Cresso M, Clerici N, Sanchez A, Jaramillo F. 2020. Future Climate Change Renders Unsuitable Conditions for Paramo Ecosystems in Colombia. Sustainability. 12(20):8373. doi:10.3390/su12208373.

Dahinden F, Fischer EM, Knutti R. 2017. Future local climate unlike currently observed anywhere. Environmental Research Letters. 12(8):084004. doi:10.1088/1748-9326/aa75d7.

Deksne, G., Davidson, R.K., Buchmann, K., Kärssin, A., Kirjušina, M., Gavarāne, I., Miller, A.L., Pálsdóttir, G.R., Robertson, L.J., Mørk, T., Oksanen, A., Palinauskas, V., Jokelainen, P., 2020. Parasites in the changing world – Ten timely examples from the Nordic-Baltic region. Parasite Epidemiology and Control 10. https://doi.org/10.1016/j.parepi.2020.e00150

Destouni G, Persson K, Prieto C, Jarsjö J. 2010. General Quantification of Catchment-Scale Nutrient and Pollutant Transport through the Subsurface to

Surface and Coastal Waters. Environmental Science & Technology 44:2048–2055. doi:10.1021/es902338y. Publisher: American Chemical Society

Dronkers J, Stojanovic T. 2016. Socio-economic Impacts—Coastal Management and Governance. In: M Quante, F Colijn, editors. North Sea Region Climate Change Assessment. Regional Climate Studies. Cham: Springer International Publishing. p. 475–488. doi:10.1007/978-3-319-39745-019

Dryselius, R., Hjertqvist, M., Mäkitalo, S., Lindblom, A., Lilja, T., Eklöf, D., Lindström, A., 2019. Large outbreak of tularaemia, central Sweden, July to September 2019. Euro Surveill 24. https://doi.org/10.2807/1560-7917.ES.2019.24.42.1900603

Eckersten H, Karlsson S, Torssell B. 2008. Climate change and agricultural land use in Sweden. Report 7. Uppsala. ISBN: 9789185911578 ISSN: 1653-5375 Issue: 7 Num Pages: 136

Eckersten, H., Sveriges lantbruksuniversitet, Institutionen för växtproduktionsekologi, 2008. Bedömningar av klimatförändringars effekter på växtproduktion inom jordbruket i Sverige. Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala

EEA. 2020. Soil contamination widespread in Europe — European Environment Agency: https://www.eea.europa.eu/highlights/soil-contamination-widespread-in-europe

EEA. 2020a. Key observed and projected climate change and impacts for the main regions in Europe — European Environment Agency :https://www.eea.europa.eu/data-and-maps/figures/key-past-and-projected-impacts-and-effects-on-sectors-for-the-main-biogeographic-regions-of-europe-5

EEA. 2020b. Meteorological and hydrological droughts in Europe — European Environment Agency :https://www.eea.europa.eu/data-and-maps/indicators/river-flow-drought-3/assessment

Eklund, A., Stensen, K., Alavi, G., Jacobsson, K., 2018. Sveriges stora sjöar idag och i framtiden: Klimatets påverkan på Vänern, Vättern, Mälaren och Hjälmaren. Kunskapssammanställning februari 2018. (No. 49), Klimatologi

Elsäkerhetsverket, 2018. Elsäkerhetsverkets handlingsplan för klimatanpassning 57.Statens Fastighetsverk, 2020. SFV:s arbete enligt förordning (2018:1428) om myndigheters klimatanpassningsarbete

Eriksson M, Ebert K, Jarsjö J. 2018. Well Salinization Risk and Effects of Baltic Sea Level Rise on the Groundwater-Dependent Island of O¨ land, Sweden. Water 10:141. doi:10.3390/w10020141. Number: 2 Publisher: Multidisciplinary Digital Publishing Institute

Felton, A., Ellingson, L., Andersson, E., Drössler, L., Blennow, K., 2010. Adapting production forests in southern Sweden to climate change: Constraints and opportunities for risk spreading. International Journal of Climate Change Strategies and Management 2, 84–97. https://doi.org/10.1108/17568691011020274

Field CB. 2014. Climate Change 2014 – Impacts, Adaptation and Vulnerability: Regional Aspects. Cam- bridge University Press

Folkhälsomyndigheten, 2014. Svenskt arbete mot antibiotikaresistens. Folkhälsomyndigheten

Folkhälsomyndigheten, 2015. Hälsoeffekter av höga temperaturer. En kunskapssammanställning. Folkhälsomyndigheten

Folkhälsomyndigheten, 2016. Exempel på dricksvattenburna utbrott i Sverige [WWW Document]. URL http://www.folkhalsomyndigheten.se/smittskydd-beredskap/smittsamma-sjukdomar/vattenburen-smitta/exempel-pa-dricksvattenburna-utbrott-i-sverige/ (accessed 10.2.20)

Folkhälsomyndigheten, 2017a. Folkhälsa i ett förändrat klimat - Handlingsplan för klimatanpassning år 2017-2020 28

Folkhälsomyndigheten, 2017b. Sjukdomsinformation om vibrioinfektion [WWW Document]. URL http://www.folkhalsomyndigheten.se/smittskydd-beredskap/smittsamma-sjukdomar/vibrioinfektioner/ (accessed 10.2.20)

Folkhälsomyndigheten, 2018a. Ökad dödlighet under sommarens värmebölja [WWW Document]. Folkhälsomyndigheten. URL http://www.folkhalsomyndigheten.se/nyheter-och-press/nyhetsarkiv/2018/december/okad-dodlighet-under-sommarens-varmebolja/ (accessed 10.13.20)

Folkhälsomyndigheten, 2018b. Värmestress i urbana inomhusmiljöer 42

Folkhälsomyndigheten, 2019. Kartläggning av bebyggelse med risk för höga temperaturer 29

Franzén, M., Ockinger, E., Öckinger, E., 2012. Climate-driven changes in pollinator assemblages during the last 60 years in an Arctic mountain region in Northern Scandinavia. Journal of Insect Conservation 16, 227–238. https://doi.org/10.1007/s10841-011-9410-y

Garamszegi, L.Z., 2011. Climate change increases the risk of malaria in birds. Global Change Biology 17, 1751–1759. https://doi.org/10.1111/j.1365-2486.2010.02346.x

Giorgi, F., Jones, C., Asrar, G.R., 2009. Addressing Climate Information Needs at the Regional Level: the CORDEX Framework (Bulletin No. Wol. 58 (3)). WMO

Graham LP. 2004. Climate Change Effects on River Flow to the Baltic Sea. AMBIO: A Journal of the Human Environment 33:235–241. doi:10.1579/0044-7447-33.4.235. Publisher: Royal Swedish Academy of Sciences

Grünig, M., Calanca, P., Mazzi, D., Pellissier, L., 2020a. Inflection point in climatic suitability of insect pest species in Europe suggests non-linear responses to climate change. Global Change Biology n/a, 1–12. https://doi.org/10.1111/gcb.15313

Grünig, M., Mazzi, D., Calanca, P., Karger, D.N., Pellissier, L., 2020b. Crop and forest pest metawebs shift towards increased linkage and suitability overlap under climate change. Commun Biol 3, 233. https://doi.org/10.1038/s42003-020-0962-9

Gustafsson, E., Gustafsson, B.G., 2020. Future acidification of the Baltic Sea – A sensitivity study. Journal of Marine Systems 211, 103397. https://doi.org/10.1016/j.jmarsys.2020.103397

Haeberli, W., Schaub, Y., Huggel, C., 2017. Increasing risks related to landslides from degrading permafrost into new lakes in de-glaciating mountain ranges. Geomorphology 293, 405–417. https://doi.org/10.1016/j.geomorph.2016.02.009

Hanna E, Huybrechts P, Janssens I, Cappelen J, Steffen K, Stephens A. 2005. Runoff and mass balance of the Greenland ice sheet: 1958–2003. Journal of Geophysical Research: Atmospheres 110. doi:10.1029/ 2004JD005641. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004JD005641

Hansson, M., Viktorsson, L., Andersson, L., 2018. Oxygen Survey in the Baltic Sea 2018 - Extent of Anoxia and Hypoxia, 1960-2018 (No. REPORT OCEANOGRAPHY No. 65, 2018). Swedish Meteorological and Hydrological Institute

Havs- och vattenmyndigheten, 2017. Övervakning av främmande arter [WWW Document]. URL. http://www.havochvatten.se/overvakning-och-uppfoljning/miljoovervakning/overvakning-av-frammande-arter.html (accessed 11.8.20)

Havs- och vattenmyndigheten, 2018. Havs- och vattenmyndighetens arbete med handlingsplan för klimatanpassning. Report 2018:9

Havs- och vattenmyndigheten, 2019. Algblomning [WWW Document]. Havs- och vattenyndigheten. URL http://www.havochvatten.se/miljopaverkan-och-atgarder/miljopaverkan/overgodning/algblomning.html (accessed 10.5.20)

Havs- och vattenmyndigheten, 2020a. Fosfor i sjöar och vattendrag [WWW Document]. URL http://www.havochvatten.se/data-kartor-och-rapporter/data-och-statistik/officiell-statistik/officiell-statistik---havs--och-vattenmiljo/fosfor-i-sjoar-och-vattendrag.html (accessed 11.2.20)

Havs- och vattenmyndigheten, 2020b. Kväve i sjöar och vattendrag [WWW Document]. URL http://www.havochvatten.se/data-kartor-och-rapporter/data-och-statistik/officiell-statistik/officiell-statistik---havs--och-vattenmiljo/kvave-i-sjoar-och-vattendrag.html (accessed 11.2.20)

Havs- och vattenmyndigheten, 2020c. Övergödning [WWW Document]. URL http://www.havochvatten.se/miljopaverkan-och-atgarder/miljopaverkan/overgodning.html (accessed 11.2.20)

Havs- och vattenmyndigheten, 2020d. Tillförsel av kväve till kusten [WWW Document]. URL http://www.havochvatten.se/data-kartor-och-rapporter/data-och-statistik/officiell-statistik/officiell-statistik---havs--och-vattenmiljo/tillforsel-av-kvave-till-kusten.html (accessed 11.2.20)

Havs- och vattenmyndigheten, 2020e. Tillförsel av fosfor till kusten [WWW Document]. URL http://www.havochvatten.se/data-kartor-och-rapporter/data-och-statistik/officiell-statistik/officiell-statistik---havs--och-vattenmiljo/tillforsel-av-fosfor-till-kusten.html (accessed 11.2.20)

Henriksen HJ, Rosenbom A, van der Keur P, Kjaer J, Sonnenborg T, Olesen JE, Nistrup Joergensen L, Boessing Christensen O. 2013. Prediction of climate impacts on pesticide leaching to the aquatic environments

Hof, A.R., Jansson, R., Nilsson, C., 2012. Future Climate Change Will Favour Non-Specialist Mammals in the (Sub)Arctics. PLoS ONE 7, e52574. https://doi.org/10.1371/journal.pone.0052574

Hof, A.R., Svahlin, A., 2016. The potential effect of climate change on the geographical distribution of insect pest species in the Swedish boreal forest. Scandinavian Journal of Forest Research 31, 29–39. https://doi.org/10.1080/02827581.2015.1052751

Hofmeester, T.R., Young, S., Juthberg, S., Singh, N.J., Widemo, F., Andrén, H., Linnell, J.D.C., Cromsigt, J.P.G.M., 2020. Using by-catch data from wildlife surveys to quantify climatic parameters and timing of phenology for plants and animals using camera traps. Remote Sensing in Ecology and Conservation 6, 129–140. https://doi.org/10.1002/rse2.136

IPCC. 2014. Climate change 2014: impacts, adaptation, and vulnerability: Part A: Global and Sectoral Aspects, Working Group II contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press. OCLC: ocn900613741

Jaenson, T.G.T., Hjertqvist, M., Bergström, T., Lundkvist, Å., 2012a. Why is tick-borne encephalitis increasing? A review of the key factors causing the increasing incidence of human TBE in Sweden. Parasites & Vectors 5, 1–13. https://doi.org/10.1186/1756-3305-5-184

Jaenson, T.G.T., Jaenson, D.G., Eisen, L., Petersson, E., Lindgren, E., 2012b. Changes in the geographical distribution and abundance of the tick Ixodes ricinus during the past 30 years in Sweden. Parasites Vectors 5, 8. https://doi.org/10.1186/1756-3305-5-8

Jaenson, T.G.T., Petersson, E.H., Jaenson, D.G.E., Kindberg, J., Pettersson, J.H.-O., Hjertqvist, M., Medlock, J.M., Bengtsson, H., 2018. The importance of wildlife in the ecology and epidemiology of the TBE virus in Sweden: incidence of human TBE correlates with abundance of deer and hares. Parasites Vectors 11, 477. https://doi.org/10.1186/s13071-018-3057-4

Jägermeyr J, Gerten D, Schaphoff S, Heinke J, Lucht W, Rockström J. 2016. Integrated crop water management might sustainably halve the global food gap. Environmental Research Letters 11:025002. doi:10.1088/17489326/11/2/025002. Publisher: IOP Publishing.

Jaramillo F, Destouni G. 2014. Developing water change spectra and distinguishing change drivers worldwide. Geophysical Research Letters. 41(23):8377–8386. doi:10.1002/2014GL061848.

Jaramillo, F., Cory, N., Arheimer, B., Laudon, H., van der Velde, Y., Hasper, T.B., Teutschbein, C., 1985, Uddling, J., 2018. Dominant effect of increasing forest biomass on evapotranspiration: Interpretations of movement in Budyko Space. Hydrology and Earth System Sciences 22, 567–580. https://doi.org/10.5194/hess-22-567-2018

Jarsjö J, Andersson-Sköld Y, Fröberg M, Pietroń J, Borgström R, Löv Kleja DB. 2020. Projecting impacts of climate change on metal mobilization at contaminated sites: Controls by the groundwater level. Science of The Total Environment 712:135560. doi:10.1016/j.scitotenv.2019.135560

Jarsjö J, Chalov SR, Pietroń J, Alekseenko AV, Thorslund J. 2017a. Patterns of soil contamination, erosion and river loading of metals in a gold mining region of northern Mongolia. Regional Environmental Change 17:1991–2005. doi:10.1007/s10113-017-1169-6

Jarsjö J, Törnqvist R, Su Y. 2017b. Climate-driven change of nitrogen retention–attenuation near irrigated fields: multi-model projections for Central Asia. Environmental Earth Sciences 76:117. doi:10.1007/ s12665-017-6418-y

Johansson W, Klingspor P. 1977. Bevattning inom lantbruket 1976. 100

Jonsson, T., Setzer, M., 2015. A freshwater predator hit twice by effects of warming across trophic levels. Nature Communications 6. https://doi.org/10.1038/ncomms6992
Jordbruksverket, 2012a. Vässa växtskyddet för framtidens klimat Hur vi förebygger och hanterar ökade problem i ett förändrat klimat (No. Rapport 2012:10)

Jordbruksverket, 2012b. Ett klimatvänligt jordbruk 2050. Rapport 2012:35

Jordbruksverket, 2017. Handlingsplan för klimatanpassning Jordbruksverkets arbete med klimatanpassning inom jordbruks- och trädgårdssektorn. Rapport 2017:7

Jordbruksverket, 2018a. Hur kan den svenska jordbrukssektorn bidra till att vi når det nationella klimatmålet? Sammanställning av pågående arbete och framtida insatsområden. Rapport 2018:1

Jordbruksverket, 2018b. Avvattning av jordbruksmark i ett förändrat klimat. Rapport 2018:19

Jordbruksverket, 2018c. Jordbrukets behov av vattenförsörjning Rapport 2018:18.

Jordbruksverket, 2019. Långsiktiga effekter av torkan 2018 - och hur jordbruket kan bli mer motståndskraftigt mot extremväder (No. Rapport 2019:13).

Juhola, S., Klein, N., Käyhkö, J., Schmid Neset, T.-S., 2017. Climate change transformations in Nordic agriculture? Journal of Rural Studies 51, 28–36. https://doi.org/10.1016/j.jrurstud.2017.01.013

Jyrkama MI, Sykes JF. 2007. The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). Journal of Hydrology 338:237–250. doi:10.1016/j.jhydrol.2007.02.036. Klassen J, Allen DM. 2017. Assessing the risk of saltwater intrusion in coastal aquifers. Journal of Hydrology 551:730–745. doi:10.1016/j.jhydrol.2017.02.044.

Katsanevakis, S., Zenetos, A., Belchior, C., Cardoso, A.C., 2013. Invading European Seas: Assessing pathways of introduction of marine aliens. Ocean & Coastal Management 76, 64–74. https://doi.org/10.1016/j.ocecoaman.2013.02.024

Keskinen, T., Lilja, J., Högmander, P., Holmes, J.A., Karjalainen, J., Marjomäki, T.J., 2012. Collapse and recovery of the European smelt (Osmerus eperlanus) population in a small boreal lake -- an early warning of the consequences of climate change. Boreal Environment Research 17, 398–410

Keskitalo, E.C.H., Bergh, J., Felton, A., Björkman, C., Berlin, M., Axelsson, P., Ring, E., Ågren, A., Roberge, J.-M., Klapwijk, M.J., Boberg, J., 2016. Adaptation to Climate Change in Swedish Forestry. Forests 7, 28. https://doi.org/10.3390/f7020028

Klimatanpassning.se, 2019. Algblomning [WWW Document]. URL https://www.klimatanpassning.se/hur-samhallet-paverkas/naturmiljo-och-ekosystem/algblomning-1.151155 (accessed 10.5.20)

Koleva N, Schneider U, Tol R. 2009. The impact of weather variability and climate change on pesticide applications in the US - An empirical investigation. Research unit Sustainability and Global Change, Hamburg University, Working Papers.

Kritzberg, E.S., Hasselquist, E.M., Škerlep, M., Löfgren, S., Olsson, O., Stadmark, J., Valinia, S., Hansson, L.-A., Laudon, H., 2020. Browning of freshwaters: Consequences to ecosystem services, underlying drivers, and potential mitigation measures. Ambio 49, 375–390. https://doi.org/10.1007/s13280-019-01227-5

KUNDZEWICZ ZW, MATA LJ, ARNELL NW, DÖLL P, JIMENEZ B, MILLER K, OKI T, S ̦EN Z, SHIKLOMANOV I. 2008. The implications of projected climate change for freshwater resources and their management. Hydrological Sciences Journal 53:3–10. doi:10.1623/hysj.53.1.3. Publisher:Taylor & Francis eprint: https://doi.org/10.1623/hysj.53.1.3

Kyllmar, K., Forsberg, L.S., Andersson, S., Mårtensson, K., 2014. Small agricultural monitoring catchments in Sweden representing environmental impact. Agriculture, Ecosystems & Environment, Nitrogen losses from agriculture in the Baltic Sea region 198, 25–35. https://doi.org/10.1016/j.agee.2014.05.016

Lamichhane, J., Barzman, M., Booij, K., Boonekamp, P., Desneux, N., Huber, L., Kudsk, P., Langrell, S., Ratnadass, A., Ricci, P., Sarah, J.-L., Messéan, A., 2015. Robust cropping systems to tackle pests under climate change. A review. Agronomy for Sustainable Development (Springer Science & Business Media B.V.) 35, 443–459. https://doi.org/10.1007/s13593-014-0275-9

Langbein, W.B., 1949. Annual Runoff in the United States.

Langvall, O., 2011. Impact of climate change, seedling type and provenance on the risk of damage to Norway spruce (Picea abies (L.) Karst.) seedlings in Sweden due to early summer frosts. Scandinavian Journal Of Forest Research 26, 56–63. https://doi.org/10.1080/02827581.2011.564399

Laube, J., Sparks, T.H., Estrella, N., Höfler, J., Ankerst, D.P., Menzel, A., 2014. Chilling outweighs photoperiod in preventing precocious spring development. Global Change Biology 20, 170–182. https://doi.org/10.1111/gcb.12360

Lenoir, J., Hattab, T., Pierre, G., 2017. Climatic microrefugia under anthropogenic climate change: implications for species redistribution. Ecography 40, 253–266. https://doi.org/10.1111/ecog.02788

Lewan E, Kreuger J, Jarvis N. 2009. Implications of precipitation patterns and antecedent soil water content for leaching of pesticides from arable land. Agricultural Water Management 96:1633–1640. doi:10.1016/j.agwat.2009.06.006

Lindberg, F., Johansson, L., Thorsson, S., 2012. Rumslig variation av strålningstemperatur i Hjorthagen och på Östermalm 20

Lindhusen Lindhé, E., Hjertqvist, M., Wahab, T., 2018. Outbreak of tularaemia connected to a contaminated well in the Västra Götaland region in Sweden. Zoonoses & Public Health 65, 142–146. https://doi.org/10.1111/zph.12382

Livsmedelsverket. 2020. Klimatanpassningsåtgärder. : https://www.livsmedelsverket.se/produktion-handel–kontroll/dricksvattenproduktion/kaskad-handbok-for-klimatanpassning dricksvattenproduktion/ klimatanpassningsatgarder

Loarie, S.R., Duffy, P.B., Hamilton, H., Asner, G.P., Field, C.B., Ackerly, D.D., 2009. The velocity of climate change. Nature 462, 1052–1055. https://doi.org/10.1038/nature08649

Lu, X., Lu, Y., Chen, D., Su, C., Song, S., Wang, T., Tian, H., Liang, R., Zhang, M., Khan, K., 2019. Climate change induced eutrophication of cold-water lake in an ecologically fragile nature reserve. Journal of Environmental Sciences 75, 359–369. https://doi.org/10.1016/j.jes.2018.05.018

Lundmark, T., Bergh, J., Hofer, P., Lundström, A., Nordin, A., Poudel, B.C., Sathre, R., Taverna, R., Werner, F., 2014. Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation. Forests 5, 557–578. https://doi.org/10.3390/f5040557

Länsstyrelsen Blekinge län, 2014. Anpassning till ett förändrat klimat Blekinges regionala handlingsplan (No. 2014:12)

Länsstyrelsen i Stockholms län, 2019. Värmekartläggning av Stockholms län, Faktablad.
Länsstyrelsen i Västra Götalands län, 2017. Regional handlingsplan för klimatanpassning i Västra Götalands län 2018-2020 (No. 45)

Länsstyrelsen Jämtlands län, 2018. Karsa – Klimatanpassning och risk- och sårbarhetsarbete i Jämtlands län 112

Länsstyrelsen Kalmar län, Lars Ljungström, 2012. Regional handlingsplan för klimatanpassning Kalmar län

Länsstyrelsen i Kronobergs Län, 2016. Regional Handlingsplan för Klimatanpassning i Kronobergs Län (01)

Länsstyrelsen Skåne, 2020. Regional handlingsplan för klimatanpassning för Länsstyrelsen Skåne 2020–2024 (No. 03)

Länsstyrelsen Stockholm, 2014. Ett robust samhälle Regional handlingsplan för klimatanpassning i Stockholms län (No. 14)

Länsstyrelsen Västerbotten, 2014. Klimatanpassa Västerbotten Regional handlingsplan för klimatanpassning 2014–2016 Vägledning för det fortsatta lokala och regionala klimatanpassningsarbetet

Länsstyrelsen Västmanlands län, 2013. Klimatstrategi för Västmanlands län (No. 12)

Länsstyrelsen Östergötland, 2014. Regional handlingsplan för klimatanpassning i Östergötland (No. 12). Länsstyrelsen Östergötland, Linköping

Ma, Y., Vigouroux, G., Kalantari, Z., Goldenberg, R., Destouni, G., 2020. Implications of Projected Hydroclimatic Change for Tularemia Outbreaks in High-Risk Areas across Sweden. International Journal of Environmental Research and Public Health 17, 6786–6786. https://doi.org/10.3390/ijerph17186786

Mazi K, Koussis AD, Destouni G. 2013. Tipping points for seawater intrusion in coastal aquifers under rising sea level. Environmental Research Letters 8:014001. doi:10.1088/1748-9326/8/1/014001

McElroy, S., Schwarz, L., Green, H., Corcos, I., Guirguis, K., Gershunov, A., Benmarhnia, T., 2020. Defining heat waves and extreme heat events using sub-regional meteorological data to maximize benefits of early warning systems to population health. Science of The Total Environment 721, 137678. https://doi.org/10.1016/j.scitotenv.2020.137678

Meier MF, Dyurgerov MB, Rick UK, O'Neel S, Pfeffer WT, Anderson RS, Anderson SP, Glazovsky AF. 2007. Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century. Science 317:1064–1067. doi:10. 1126/science.1143906. Publisher: American Association for the Advancement of Science Section: Report. Ministry of the Environment and Energy. 2017. Sweden's Seventh National Communication on Climate Change

Meier, H.E.M., Eilola, K., Almroth-Rosell, E., Schimanke, S., Kniebusch, M., Höglund, A., Pemberton, P., Liu, Y., Väli, G., Saraiva, S., 2019. Disentangling the impact of nutrient load and climate changes on Baltic Sea hypoxia and eutrophication since 1850. Climate Dynamics: Observational, Theoretical and Computational Research on the Climate System 53, 1145. https://doi.org/10.1007/s00382-018-4296-y

Mulligan CN, Yong RN, Gibbs BF. 2001. Remediation technologies for metal-contaminated soils and ground- water: an evaluation. Engineering Geology 60:193–207. doi:10.1016/S0013-7952(00)00101-0

Müller, J. d., Schneider, B., Rehder, G., 2016. Long-term alkalinity trends in the Baltic Sea and their implications for CO2-induced acidification. Limnology and Oceanography 61, 1984–2002. https://doi.org/10.1002/lno.10349

Myndigheten för samhällsskydd och beredskap. 2018. Översyn av områden med betydande översvämningsrisk: enligt förordning (2009:956) om översvämningsrisker :84

Nam, W.-H., Choi, J.-Y., Yoo, S.-H., Jang, M.-W., 2012. A decision support system for agricultural drought management using risk assessment. Paddy and Water Environment 10, 197. https://doi.org/10.1007/s10333-012-0329-z

Naturvårdsverket, 2019a. Fördjupad analys av den svenska klimatomställningen: industrin i fokus (No. 6911)

Naturvårdsverket, 2019b. Handlingsplan för Naturvårdsverkets arbete med klimatanpassning

Naturvårdsverket, 2020a. Invasiva främmande arter – artfakta [WWW Document]. Naturvårdsverket. URL https://www.naturvardsverket.se/Sa-mar-miljon/Vaxter-och-djur/Frammande-arter/Invasiva-frammande-arter/ (accessed 11.6.20)

Naturvårdsverket, 2020b. Miljöövervakning av invasiva främmande arter i sötvatten. Naturvårdsverket. URL https://www.naturvardsverket.se/Nyheter-och-pressmeddelanden/Nyhetsbrev/nyhetsbrev-invasiva-frammande-arter/Artiklar-2019/Miljoovervakning-av-invasiva-frammande-arter-i-sotvatten/(accessed 11.8.20)

Naturvårdsverket, 2020c. National Land Cover Database : http://www.swedishepa.se/State-of-the- environment/Maps-and-map-services/National-Land-Cover-Database/

Nellbring, S., Sverige, Naturvårdsverket, 2011. Övervakning av främmande arter i Mälaren. Naturvårdsverket, Stockholm

Neset, T.-S., Wiréhn, L., Klein, N., Käyhköb, J., Juhola, S., 2019. Maladaptation in Nordic agriculture. Climate Risk Management 23, 78–87. https://doi.org/10.1016/j.crm.2018.12.003

Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ. 2015. Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLOS ONE 10:e0118571. doi: 10.1371/journal.pone.0118571. Publisher: Public Library of Science

Nicholls RJ, Marinova N, Lowe JA, Brown S, Vellinga P, de Gusmão D, Hinkel J, Tol RSJ. 2011. Sea level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369:161–181. doi: 10.1098/rsta.2010.0291. Publisher: Royal Society

Nolan BT, Dubus IG, Surdyk N, Fowler HJ, Burton A, Hollis JM, Reichenberger S, Jarvis NJ. 2008. Identification of key climatic factors regulating the transport of pesticides in leaching and to tile drains. Pest Management Science 64:933–944. doi: https://doi.org/10.1002/ps.1587

Nunes, A.L., Katsanevakis, S., Zenetos, A., Cardoso, A.C., 2014. Gateways to alien invasions in the European seas. AI9,133–144. https://doi.org/10.3391/ai.2014.9.2.02

Nygren M, Giese M, Kløve B, Haaf E, Rossi PM, Barthel R. 2020. Changes in seasonality of groundwater level fluctuations in a temperate-cold climate transition zone.Journal of Hydrology X 8:100062.doi:10.1016/j.hydroa.2020.100062

Okkonen J, Kløve B. 2011. A sequential modelling approach to assess groundwater–surface water resources in a snow dominated region of Finland. Journal of Hydrology 411:91–107. doi:10.1016/j.jhydrol.2011.09.038

Olesen JE, Trnka M, Kersebaum KC, Skjelvåg AO, Seguin B, Peltonen-Sainio P, Rossi F, Kozyra J, Micale F. 2011. Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy 34:96–112. doi:10.1016/j.eja.2010.11.003

Olofsson B. 1996. Salt Groundwater in Sweden - Occurrence and Origin :10

Olsson J, Foster K. 2014. Short-term precipitation extremes in regional climate simulations for Sweden. Hydrology Research 45:479–489. doi:10.2166/nh.2013.206. Publisher: IWA Publishing

Olson DM, Dinerstein E. 2002. The Global 200: Priority Ecoregions for Global Conservation. Annals of the Missouri Botanical Garden. 89(2):199–224. doi:10.2307/3298564.

Omstedt, A., Edman, M., Claremar, B., Frodin, P., Gustafsson, E., Humborg, C., Hägg, H., Mörth, M., Rutgersson, A., Schugers, G., Smith, B., Wällstedt, T., Yurova, A., 2012. Future changes in the Baltic Sea acid-base (pH) and oxygen balances. Tellus. Series B, Chemical and physical meteorology 64. https://doi.org/10.3402/tellusb.v64i0.19586

Omstedt, A., Humborg, C., Pempkowiak, J., Perttila, M., Rutgersson, A., Schneider, B., Smith, B., Pertillä, M., Pemkowiak, J., Perttilä, M., 2014. Biogeochemical control of the coupled CO2-O2 system of the Baltic Sea: A review of the results of Baltic-C. Ambio 43, 49–59. https://doi.org/10.1007/s13280-013-0485-4

Ou T. 2017. Droughts and wildfires in Sweden: past variation and future projection : https://www.msb.se/sv/publikationer/droughts-and-wildfires-in-sweden–past-variation-and-future- projection-forskningstudie/

Oudin Åström, D., Åström, C., Forsberg, B., Vicedo-Cabrera, A.M., Gasparrini, A., Oudin, A., Sundquist, K., 2020. Heat wave–related mortality in Sweden: A case-crossover study investigating effect modification by neighbourhood deprivation. Scand J Public Health 48, 428–435. https://doi.org/10.1177/1403494818801615

Patterson D, Westbrook J, Joyce R, Lingren P, Rogasik J. 1999. Weeds, insects, and diseases. Climatic Change 43:711–727. doi:10.1023/A:1005549400875

Persson K, Jarsjö J, Destouni G. 2011. Diffuse hydrological mass transport through catchments: scenario analysis of coupled physical and biogeochemical uncertainty effects. Hydrology and Earth System Sciences 15:3195–3206. doi: https://doi.org/10.5194/hess-15-3195-2011. Publisher: Copernicus GmbH

Peterson, A.T., 2003. Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. Global Change Biology 9, 647–655. https://doi.org/10.1046/j.1365-2486.2003.00616.x

Piccolroaz, S., Toffolon, M., Majone, B., 2015. The role of stratification on lakes' thermal response: The case of Lake Superior. Water Resources Research 51, 7878–7894. https://doi.org/10.1002/2014WR016555

Piccolroaz, S., Woolway, R.I., Merchant, C.J., 2020. Global reconstruction of twentieth century lake surface water temperature reveals different warming trends depending on the climatic zone. Climatic Change: An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change 160, 427. https://doi.org/10.1007/s10584-020-02663-z

Piemontese L, Fetzer I, Rockström J, Jaramillo F. Future Hydroclimatic Impacts on Africa: Beyond the Paris Agreement. Earth's Future. 0(0). doi:10.1029/2019EF001169. [accessed 2019 Jul 20]. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019EF001169.

Pihlainen, S., Zandersen, M., Hyytiäinen, K., Andersen, H.E., Bartosova, A., Gustafsson, B., Jabloun, M., McCrackin, M., Meier, H.E.M., Olesen, J.E., Saraiva, S., Swaney, D., Thodsen, H., 2020. Impacts of changing society and climate on nutrient loading to the Baltic Sea. Science of The Total Environment 731, 138935. https://doi.org/10.1016/j.scitotenv.2020.138935

Porkka M, Gerten D, Schaphoff S, Siebert S, Kummu M. 2016. Causes and trends of water scarcity in food production. Environmental Research Letters 11:015001. doi:10.1088/1748-9326/11/1/015001. Publisher: IOP Publishing

Prudhomme C, Giuntoli I, Robinson EL, Clark DB, Arnell NW, Dankers R, Fekete BM, Franssen W, Gerten D, Gosling SN, Hagemann S, Hannah DM, Kim H, Masaki Y, Satoh Y, Stacke T, Wada Y, Wisser D. 2014. Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. Proceedings of the National Academy of Sciences 111:3262–3267. doi:10.1073/pnas.1222473110. Publisher: National Academy of Sciences Section: Physical Sciences.1

Raguž V, Jarsjö J, Grolander S, Lindborg R, Avila R. 2013. Plant uptake of elements in soil and pore water: Field observations versus model assumptions.

Journal of Environmental Management 126:147–156. doi: 10.1016/j.jenvman.2013.03.055

Rankka K, Rydell B. 2005. Erosion och översvämningar: Underlag för handlingsplan för att förutse och förebygga naturolyckor i Sverige vid förändrat klimat

Rasmussen P, Sonnenborg T, G G, Hinsby K. 2013. Assessing impacts of climate change, sea level rise, and drainage canals on saltwater intrusion to coastal aquifer. Hydrology and Earth System Sciences 17:421–443. doi:10.5194/hess-17-421-2013

Regeringskansliet, R. och, 2019. Jordbruksverket betalar ut över en miljard i stöd efter torkan sommaren 2018 [WWW Document]. Regeringskansliet. URL https://www.regeringen.se/pressmeddelanden/2019/04/jordbruksverket-betalar-ut-over-en-miljard-i-stod-efter-torkan-sommaren-2018/ (accessed 10.16.20)

Richardson, A.D., Hufkens, K., Milliman, T., Aubrecht, D.M., Furze, M.E., Seyednasrollah, B., Krassovski, M.B., Latimer, J.M., Nettles, W.R., Heiderman, R.R., Warren, J.M., Hanson, P.J., 2018. Ecosystem warming extends vegetation activity but heightens vulnerability to cold temperatures. Nature 560, 368–371. https://doi.org/10.1038/s41586-018-0399-1

Rocklöv, J., Forsberg, B., 2008. The effect of temperature on mortality in Stockholm 1998—2003: A study of lag structures and heatwave effects. Scand J Public Health 36, 516–523. https://doi.org/10.1177/1403494807088458

Rocklöv, J., Forsberg, B., Ebi, K., Bellander, T., 2014. Susceptibility to mortality related to temperature and heat and cold wave duration in the population of Stockholm County, Sweden. Global Health Action 7, 1-N.PAG. https://doi.org/10.3402/gha.v7.22737

Rodhe A, Lindström G, Dahné J. 2009. Grundvattennivåer i ett förändrat klimat :44

Rodríguez-Verdugo, A., Lozano-Huntelman, N., Cruz-Loya, M., Savage, V., Yeh, P., 2020. Compounding Effects of Climate Warming and Antibiotic Resistance. iScience 23. https://doi.org/10.1016/j.isci.2020.101024

Rohat, G., Flacke, J., Dosio, A., Pedde, S., Dao, H., van Maarseveen, M., 2019. Influence of changes in socioeconomic and climatic conditions on future heat-related health challenges in Europe. Global and Planetary Change 172, 45–59. https://doi.org/10.1016/j.gloplacha.2018.09.013

Roos, J., Hopkins, R., Kvarnheden, A., Dixelius, C., 2011. The impact of global warming on plant diseases and insect vectors in Sweden. European Journal of Plant Pathology 129, 9–19. https://doi.org/10.1007/s10658-010-9692-z

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J., Schaphoff, S., 2008. Agricultural green and blue water consumption and its influence on the global water system. Water Resources Research 44. https://doi.org/10.1029/2007WR006331

Rydén, P., Sjöstedt, A., Johansson, A., 2009. Effects of climate change on tularaemia disease activity in Sweden. Global Health Action 2, 91–97. https://doi.org/10.3402/gha.v2i0.2063

Rötter, R.P., Höhn, J.G., Fronzek, S., 2012. Projections of climate change impacts on crop production: A global and a Nordic perspective. Acta Agriculturae Scandinavica, Section A — Animal Science 62, 166–180. https://doi.org/10.1080/09064702.2013.793735

Sametinget, 2017. Handlingsplan för samiska näringar och samisk kultur

Sandström, A., Ragnarsson Stabo, H., Axenrot, T., Bergstrand, E., 2014. Has climate variability driven the trends and dynamics in recruitment of pelagic fish species in Swedish Lakes Vanern and Vattern in recent decades? Aquatic Ecosystem Health & Management 17, 349–356. https://doi.org/10.1080/14634988.2014.975668

Saraiva, S., Markus Meier, H.E., Andersson, H., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R., Eilola, K., 2019. Baltic Sea ecosystem response to various nutrient load scenarios in present and future climates. Clim Dyn 52, 3369–3387. https://doi.org/10.1007/s00382-018-4330-0

Sari Kovats, R., Valentini, R., Bouwer, L.M., Georgopoulou, E., Jacob, D., Martin, E., Rounsevell, M., Soussana, J.-F., 2014. Europe. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 1267–1326

SCB. 2017. Environmental Accounts MIR 2017:1, Water Use in Sweden 2015. :57

Schiedek D, Sundelin B, Readman JW, Macdonald RW. 2007. Interactions between climate change and contaminants. Marine Pollution Bulletin 54:1845–1856. doi:10.1016/j.marpolbul.2007.09.020

Schmid, M., Köster, O., 2016. Excess warming of a Central European lake driven by solar brightening. Water Resources Research 52, 8103–8116. https://doi.org/10.1002/2016WR018651

Schwartz, M.D., Ahas, R., Aasa, A., 2006. Onset of spring starting earlier across the Northern Hemisphere. Global Change Biology 12, 343–351. https://doi.org/10.1111/j.1365-2486.2005.01097.x

Seftigen K, Linderholm HW, Drobyshev I, Niklasson M. 2013. Reconstructed drought variability in south- eastern Sweden since the 1650s. International Journal of Climatology 33:2449–2458. doi:10.1002/joc.3592. eprint: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/joc.3592

SGU (2009). Sveriges Grundvattentillgångar – betydelse för näringslivsutveckling och tillväxt - Utredning på uppdrag av regeringen

SCB, 2020. The future population of Sweden 2020 - 2070. urn:nbn:se:scb-2020-be18sm2001_pdf

SGI, 2017. Hållbart markbyggande – en handlingsplan i ett föränderligt klimat. SGI Publikation 35, Statens geotekniska institut, Linköping.

SGU, 2017. Sveriges geologiska undersöknings handlingsplan för klimatanpassning. Report 2017:04

SGU. 2020. Contaminated areas :https://www.sgu.se/en/physical-planning/contaminated-areas/

SGU. 2017. Grundvattennivåer i augusti eprint: https://www.sgu.se/om-sgu/nyheter/2017/augusti/grundvattennivaer-i-augusti/

SGU. 2020 Wells: https://www.sgu.se/produkter/geologiska-data/oppna-data/grundvatten-oppna-data/brunnar/

Sherif MM, Singh VP. 1999. Effect of climate change on sea water intrusion in coastal aquifers. Hydrological Processes 13:1277–1287.

Siebert S, Burke J, Faures JM, Frenken K, Hoogeveen J, D¨oll P, Portmann FT. 2010. Groundwater use for irrigation – a global inventory. Hydrology and Earth System Sciences 14:1863–1880. doi:https://doi.org/10.5194/hess-14-1863-2010. Publisher: Copernicus GmbH

Solomon CT, Jones SE, Weidel BC, Buffam I, Fork ML, Karlsson J, Larsen S, Lennon JT, Read JS, Sadro S, Saros JE. 2015. Ecosystem Consequences of

Sterk, A., Schijven, J., de Nijs, T., de Roda Husman, A.M., 2013. Direct and Indirect Effects of Climate Change on the Risk of Infection by Water-Transmitted Pathogens. Environ. Sci. Technol. 47, 12648–12660. https://doi.org/10.1021/es403549s

Skogsstyrelsen, 2020. Klimatanpassning av skogen och skogsbruket – mål och förslag på åtgärder. Report 2019/23

Small C, Nicholls RJ. 2003. A Global Analysis of Human Settlement in Coastal Zones. Journal of Coastal Research 19:584–599. Publisher: Coastal Education & Research Foundation, Inc

SMHI, 2018. Vad är RCP? [WWW Document]. URL https://www.smhi.se/klimat/framtidens-klimat/vagledning-klimatscenarier/vad-ar-rcp-1.80271 (accessed 12.21.20)

SMHI, 2019. Varningar för höga temperaturer [WWW Document]. URL https://www.smhi.se/kunskapsbanken/meteorologi/varning-for-mycket-hoga-temperaturer-1.30684 (accessed 10.1.20)

SMHI, 2020a. Länsvisa klimatanalyser [WWW Document]. URL https://www.smhi.se/klimat/framtidens-klimat/lansanalyser/sweden/heat-wave (accessed 10.24.20)

SMHI, 2020b. Myndigheters arbete med klimatanpassning 2019 [WWW Document]. URL https://www.smhi.se/publikationer/myndigheters-arbete-med-klimatanpassning-2019-1.159759 (accessed 9.14.20)

SMHI, 2020c. Månads-, årstids- och årskartor [WWW Document]. URL https://www.smhi.se/data/meteorologi/kartor/manadsmedeltemperatur-avvikelse/arlig/2018 (accessed 12.15.20)

SMHI. 2003. The Swedish regional climate modeling program, SWECLIM, 1996-2003. Final Report

SMHI. 2019. Havsnivå – medelvattenstånd i framtiden. MHI:
https://www.smhi.se /klimat/ havet-och- klimatet/havsniva-1.120165
SMHI. 2020. Klimatscenarier

Sonesten, L., Wallman, K., Axenrot, T., Beier, U., Drakare, S., Ecke, F., Goedkoop, W., Grandin, U., Köhler, S., Segersten, J., Vrede, T., Sveriges lantbruksuniversitet, Institutionen för vatten och miljö, S. lantbruksuniversitet, 2013. Mälaren tillståndsutvecklingen 1965-2011. Sveriges lantbruksuniversitet, Institutionen för vatten och miljö, Sveriges lantbruksuniversitet, Uppsala

Spinoni, J., Naumann, G., Vogt, J., Barbosa, P., 2015. European drought climatologies and trends based on a multi-indicator approach. Global and Planetary Change 127, 50–57. https://doi.org/10.1016/j.gloplacha.2015.01.012

Spinoni, J., Vogt, J.V., Naumann, G., Barbosa, P., Dosio, A., 2018. Will drought events become more frequent and severe in Europe? International Journal of Climatology 38, 1718–1736. https://doi.org/10.1002/joc.5291

Statens Veterinärmedicinska Anstalt, Albihn, A., Alizadeh, E., Artursson, K., Axén, C., Elving, J., Eriksson, E., Gröndahl, G., Hallgren, G., Lindström, A., Nordkvist, E., Omazic, A., Pers, Y., 2019. Handlingsplan för klimatanpassning 2019 En rapport om klimatets påverkan på djuren 40

Steffens K, Jarvis N, Lewan E, Lindström B, Kreuger J, Kjellström E, Moeys J. 2015. Direct and indirect effects of climate change on herbicide leaching — A regional scale assessment in Sweden. Science of The Total Environment 514:239–249. doi:10.1016/j.scitotenv.2014.12.049

Stenrød M, Perceval J, Benoit P, Almvik M, Bolli RI, Eklo OM, Sveistrup TE, Kværner J. 2008. Cold climatic conditions: Effects on bioavailability and leaching of the mobile pesticide metribuzin in a silt loam soil in Norway. Cold Regions Science and Technology 53:4–15. doi:10.1016/j.coldregions.2007.06.007

Strandberg, G., Bärring, L., Hansson, U., Jansson, C., Kjellström, E., Kolax, M., Kupiainen, M., Nikulin, G., Samuelsson, P., Ullerstig, A., Wang, S., 2015. CORDEX scenarios for Europe from the Rossby Centre regional climate model RCA4 (No. ISSN: 0347-2116), RMK 116. SMHI, Sweden

Stroeve J, Holland MM, Meier W, Scambos T, Serreze M. 2007. Arctic sea ice decline: Faster than forecast. Geophysical Research Letters 34. doi:10.1029/2007GL029703 eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2007GL029703

Sundén G, Maxe L, Dahné J. 2010. Grundvattennivåer och vattenförsörjning vid ett förändrat klimat :46

Sutinen R, Hänninen P, Venäläinen A. 2008. Effect of mild winter events on soil water content beneath snowpack. Cold Regions Science and Technology 51:56–67. doi:10.1016/j.coldregions.2007.05.014

Swedish Commission on Climate Vulnerability. 2007. Sweden facing climate change: threats and opportunities; final report from the Swedish Commission on Climate and Vulnerability. Number 2007,60 in Statens offentliga utredningar. Stockholm: Fritze. OCLC: 404716517

Swedish EPA. 2017. Description of the management of contaminated sites 2016 (in Swedish, Lägesbeskrivning av arbetet med efterbehandling av förorenade områden 2016, Ärende nummer NV 03165–16, Skrivelse till regeringen 2017-04-06), Letter to the Government 2017-04-06, Case number NV-03165-16. :http://www.naturvardsverket.se/upload/sa-mar-miljon/mark/fororenade-omraden/lagesbeskrivning-2016-ebh-objekt.pdf

Swedish Portal For Climate Change Adaptation. 2020. Swedish Portal for Climate Change Adaptation: http://www.klimatanpassning.se/en
Sverige inför klimatförändringarna - hot och möjligheter (No. SOU 2007:60), 2007

Tallaksen LM, Van Lanen HAJ. 2004. Hydrological Drought: Processes and Estimation Methods for Stream- flow and Groundwater. Elsevier. Google-Books-ID: eXLDwgxG0ikC

Teutschbein, C., Sponseller, R.A., Grabs, T., Blackburn, M., Boyer, E.W., Hytteborn, J.K., Bishop, K., 2017. Future Riverine Inorganic Nitrogen Load to the Baltic Sea From Sweden: An Ensemble Approach to Assessing Climate Change Effects. Global Biogeochemical Cycles 31, 1674–1701. https://doi.org/10.1002/2016GB005598

Tian, L., Yuan, S., Quiring, S.M., 2018. Evaluation of six indices for monitoring agricultural drought in the south-central United States. Agricultural and Forest Meteorology 249, 107–119. https://doi.org/10.1016/j.agrformet.2017.11.024

Toffolon, M., Piccolroaz, S., Majone, B., Soja, A.-M., Peeters, F., Schmid, M., Wüest, A., 2014. Prediction of surface temperature in lakes with different morphology using air temperature. Limnology and Oceanography 59, 2185–2202. https://doi.org/10.4319/lo.2014.59.6.2185

Tóth G, Hermann T, Da Silva MR, Montanarella L. 2016. Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International 88:299–309. doi:10.1016/j.envint.2015. 12.017

Trnka M, Olesen JE, Kersebaum KC, Skjelvåg AO, Eitzinger J, Seguin B, Peltonen-Sainio P, Rötter R, Iglesias A, Orlandini S, Dubrovský M, Hlavinka P, Balek J, Eckersten H, Cloppet Calanca,P, Gobin A, Vŭcetić V, Nejedlik P, Kumar S, Lalic B, Mestre A, Rossi F, Kozyra J, Alexandrov V, Semerádová D, Zˇalud Z. 2011. Agroclimatic conditions in Europe under climate change. Global Change Biology 17:2298, 2318.doi: https://doi.org/10.1111/j.1365-2486.2011.02396.x

Tudoran, M.-M., Marquer, L., Jönsson, A.M., 2016. Historical experience (1850–1950 and 1961–2014) of insect species responsible for forest damage in Sweden: Influence of climate and land management changes. Forest Ecology and Management 381, 347–359. https://doi.org/10.1016/j.foreco.2016.09.044

Tyler, T., Herbertsson, L., Olsson, P.A., Fröberg, L., Olsson, K.-A., Svensson, Å., Olsson, O., 2018. Climate warming and land-use changes drive broad-scale floristic changes in Southern Sweden. Global Change Biology 24, 2607–2621. https://doi.org/10.1111/gcb.14031

Törnqvist R, Jarsjö J, Karimov B. 2011. Health risks from large-scale water pollution: Trends in Central Asia. Environment International 37:435–442. doi:10.1016/j.envint.2010.11.006

United Nations, 2012. Slow onset events Technical paper FCCC/TP/2012/7

van der Velde, Y., Vercauteren, N., Jaramillo, F., Dekker, S.C., Destouni, G., Lyon, S.W., 2014. Exploring hydroclimatic change disparity via the Budyko framework. Hydrological Processes 28, 4110–4118. https://doi.org/10.1002/hyp.9949

Van Lanen HAJ, Wanders N, Tallaksen LM, Van Loon AF. 2012. Hydrological drought across the world: impact of climate and physical catchment structure. Hydrology and Earth System Sciences Discussions 9:12145–12192. doi:10.5194/hessd-9-12145-2012

Van Loon AF. 2015. Hydrological drought explained. WIREs Water 2:359–392. doi:10.1002/wat2.1085. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wat2.1085.

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O.-P., Viiri, H., Ikonen, V.-P., Peltola, H., 2020. Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review. Global change biology 26, 4178–4196. https://doi.org/10.1111/gcb.15183

Vikberg E, Thunholm B, Thorsbrink M, Dahné J. 2015. Grundvattennivåer i ett förändrat klimat – nya klimatscenarier :26

Vonberg D, Vanderborght J, Cremer N, Pütz T, Herbst M, Vereecken H. 2014. 20 years of long-term atrazine monitoring in a shallow aquifer in western Germany. Water Research 50:294–306. doi:10.1016/j.watres. 2013.10.032

Voss, R., Quaas, M.F., Stiasny, M.H., Hänsel, M., Stecher Justiniano Pinto, G.A., Lehmann, A., Reusch, T.B.H., Schmidt, J.O., 2019. Ecological-economic sustainability of the Baltic cod fisheries under ocean warming and acidification. Journal of Environmental Management 238, 110–118. https://doi.org/10.1016/j.jenvman.2019.02.105

Wasof, S., Lenoir, J., Gallet-Moron, E., Jamoneau, A., Brunet, J., Cousins, S.A.O., De Frenne, P., Diekmann, M., Hermy, M., Kolb, A., Liira, J., Verheyen, K., Wulf, M., Decocq, G., 2013. Ecological niche shifts of understorey plants along a latitudinal gradient of temperate forests in north-western Europe. Global Ecology and Biogeography 22, 1130–1140

Wesström, I., Hargeby, A., Tonderski, K., Naturvårdsverket, 2017. Miljökonsekvenser av markavvattning och dikesrensning. En kunskapssammanställning

Weyhenmeyer, G.A., 2001. Warmer Winters: Are Planktonic Algal Populations in Sweden's Largest Lakes Affected? Ambio 30, 565–571

Wilhelmi, O.V., Wilhite, D.A., 2002. Assessing Vulnerability to Agricultural Drought: A Nebraska Case Study. Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards 25, 37. https://doi.org/10.1023/a:1013388814894

Williams JW, Jackson ST. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment. 5(9):475–482. doi:10.1890/070037.

Williams JW, Jackson ST, Kutzbach JE. 2007. Projected distributions of novel and disappearing climates by 2100 AD. Proceedings of the National Academy of Sciences of the United States of America. 104(14):5738–5742. doi:10.1073/pnas.0606292104.

Wivstad, M., 2010. Klimatförändringarna - en utmaning för jordbruket och Giftfri miljö. Kemikalieinspektionen PM 2/10 97

Widerström, M., Schönning, C., Lilja, M., Lebbad, M., Ljung, T., Allestam, G., Ferm, M., Björkholm, B., Hansen, A., Hiltula, J., Långmark, J., Löfdahl, M., Omberg, M., Reuterwall, C., Samuelsson, E., Widgren, K., Wallensten, A., Lindh, J., 2014. Large Outbreak of Cryptosporidium hominis Infection Transmitted through the Public Water Supply, Sweden - Volume 20, Number 4—April 2014 - Emerging Infectious Diseases journal - CDC 20. https://doi.org/10.3201/eid2004.121415

Woolway, R.I., Maberly, S.C., 2020. Climate velocity in inland standing waters. Nature Climate Change 1–6. https://doi.org/10.1038/s41558-020-0889-7

Wu WY, Lo MH, Wada Y, Famiglietti JS, Reager JT, Yeh PJF, Ducharne A, Yang ZL. 2020. Divergent effects of climate change on future groundwater availability in key mid-latitude aquifers. Nature Communications 11:3710. doi:10.1038/s41467-020-17581-y. Number: 1 Publisher: Nature Publishing Group

Wåhlström, I., Höglund, A., Almroth-Rosell, E., MacKenzie, B.R., Gröger, M., Eilola, K., Plikshs, M., Andersson, H.C., 2020. Combined climate change and nutrient load impacts on future habitats and eutrophication indicators in a eutrophic coastal sea. Limnol Oceanogr 65, 2170–2187. https://doi.org/10.1002/lno.11446

Xu Cy. 2000. Modelling the Effects of Climate Change on Water Resources in Central Sweden. Water Resources Management 14:177–189. doi:10.1023/A:1026502114663

Zohner, C. m., Renner, S. s., Benito, B. m. (2), Svenning, J.-C., 2016. Day length unlikely to constrain climate-driven shifts in leaf-out times of northern woody plants. Nature Climate Change 6, 1120–1123. https://doi.org/10.1038/nclimate3138

Åby, B.A., Kantanen, J., Aass, L., Meuwissen, T., 2014. Current status of livestock production in the Nordic countries and future challenges with a changing climate and human population growth. Acta Agriculturae Scandinavica, Section A — Animal Science 64, 73–97. https://doi.org/10.1080/09064702.2014.950321

Ågren J, Svensson R. 2007. Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH 2000 :124

Øygarden, L., Deelstra, J., Lagzdins, A., Bechmann, M., Greipsland, I., Kyllmar, K., Povilaitis, A., Iital, A., 2014. Climate change and the potential effects on runoff and nitrogen losses in the Nordic–Baltic region. Agriculture, Ecosystems & Environment, Nitrogen losses from agriculture in the Baltic Sea region 198, 114–126. https://doi.org/10.1016/j.agee.2014.06.025

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