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Impacts of future sea level rise and high water on roads, railways and environmental objects

A GIS analysis of the potential effects of increasing sea levels and highest projected high water in Scania, Sweden

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English abstract

Climate change caused by increasing emissions of greenhouse gases since the mid-19th century has amongst other things led to an increase in both melting of the cryosphere and thermal expansion in the oceans, which has caused the sea level to rise at an increasing rate over the last century. An increasing sea level could inundate land, roads and railways as well as environmental objects, and due to this, the Swedish Transport Administration incorporates climate change adaptation for e.g. sea level rise when constructing and maintaining both state-owned roads and railways as well as their side areas.

This thesis uses analyses in geographical information systems to investigate and visualize as well as calculate the statistics of the effects of future sea level rise. Several potential future sea levels as well as the highest projected high water are included in the study, with the objective to locate state-owned roads, railways and environmental objects at risk of being inundated by an increasing sea level. Sea levels up to 5.0 meters above the current ocean level are analyzed in the thesis, with an interval of 0.5 meters, and divided into four long-duration and four short-duration risk levels, based on projected sea level rises on different horizons, with or without the addition of the highest projected high water in the study area.

This study focuses on the southernmost county of Sweden, Scania, where approximately 5 % of the total area is affected by the analyzed sea levels. An increasing sea level is found to mainly affect the coastal region of Scania, but some affected land areas stretch further inland. Environmental objects are at higher risk of inundation compared to road and railway features. The highest risk of inundation is found for species rich side areas to roads and railways as well as for both existing and needed fauna passages for medium sized fauna, while other investigated features are at lower to no risk of inundation.

The effect of different sea levels differs between different areas of Scania, and 21 of the 33 municipalities in the county are affected to some extent. The percentage of investigated features within each municipality is presented, as well as a detailed study of the two most affected municipalities, Kristianstad and Vellinge. The thesis concludes that several areas and features are subject to different levels of inundation risk and suggests how preventive action could be prioritized between both features and municipalities.

Keywords: Geography, Geographical Information Systems (GIS), Sea level, Sea level rise, Climate Change.

Swedish abstract

Utsläpp av växthusgaser sedan mitten av 1800-talet har orsakat klimatförändring som bland annat leder till en ökning av både avsmältning i kryosfären och värmeutvidgning i haven, två faktorer som gjort att havsnivån stigit allt snabbare under det senaste århundradet. Havsnivåhöjning kan öka förekomsten av översvämningar av land, vägar och järnvägar samt påverka miljöobjekt, och på grund av detta integrerar Trafikverket klimatanpassning med hänsyn till bland annat stigande havsnivåer både vid nybyggnation och underhåll av det statliga väg- och järnvägsnätet samt sidoområden till dessa.

Detta examensarbete använder analyser i geografiska informationssystem för att utreda och visualisera samt ta fram statistik över effekter av framtida havsnivåer. Flera möjliga framtida havsnivåer och högsta beräknade högvattenstånd ingår i studien, där målsättningen är att lokalisera statliga vägar och järnvägar samt miljöobjekt som riskerar att översvämmas vid havsnivåökning. Ökande havsnivåer upp till 5,0 meter med ett intervall på 0,5 meter beräknas i detta arbete, där resultatet delas in i fyra långvariga och fyra kortvariga risknivåer. Dessa nivåer baseras på beräknade havsnivåförändringar med olika tidsramar, och för de kortvariga riskerna tillkommer även högsta högvatten i studieområdet.

Studien fokuserar på Sveriges sydligaste län, Skåne, där ungefär 5 % av den totala ytan påverkas av de beräknade havsnivåerna. Ökande havsnivåer påverkar enligt analyserna främst kustområden, men några påverkade områden sträcker sig även längre in i landet. Miljöobjekt har större risk att påverkas än väg- och järnvägsobjekt. De största riskerna finns hos artrika järnvägs- och vägmiljöer samt befintliga och behövda faunapassager för medelstora däggdjur medan risken är lägre eller ingen för övriga undersökta objekt.

De effekter som stigande havsnivåer visat i denna studie skiljer sig mellan olika områden i Skåne, och 21 av länets 33 kommuner påverkas på något sätt. I arbetet redovisas den andel av de undersökta objekten som påverkas av varje risknivå per kommun och en detaljstudie presenteras för de två mest påverkade kommunerna, Kristianstad och Vellinge. Slutsatsen av examensarbetet är att flera områden och undersökta objekt påverkas av olika risknivåer och förslag på hur förebyggande åtgärder kan prioriteras mellan objekt och mellan kommuner ges.

Nyckelord: Geografi, Geografiska Informationssystem (GIS), Havsnivå, Havsnivåhöjning, Klimatförändring.

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List of abbreviations and terminology

m a. s. l. – meter above sea level

m b. s. l. – meter below sea level

Chemical compounds within the thesis:

- CO_2 – carbon dioxide
- CH^4 – methane
- H_2O – water
- N_2O – nitrous oxide
- O_3 – ozone

Cryosphere – the frozen part of Earth, i.e. permafrost, inland ice, glaciers and sea ice.

Environmental objects (Sw. Miljöobjekt) – environmental objects along the state-owned roads and railways, provided through the STA's IT set-up Miljöwebb Landskap, consist of the following objects:

- Alley trees, several trees positioned together in a line along a road or railway.
- Ancient remains related to the state-owned roads
- Culturally protected bridges
- Solitary trees along the state-owned roads and railways, solitary protected trees.
- Species rich side areas to state-owned roads, an area along the road with high biodiversity
- Species rich side areas to state-owned railways, an area along the railroad with high biodiversity
- Fauna passages for water living fauna, e.g. fish. Divided into existing passages and locations where there is a need for the creation of a passage
- Fauna passages for medium sized fauna, e.g. otters. Divided into existing passages and locations where there is a need for the creation of a passage
- Fauna passages for large fauna, e.g. elks and deer.
- Fauna passages for amphibians and reptiles, e.g. frogs. Divided into existing passages and locations where there is a need for the creation of a passage

Feature – environmental objects as well as road and railway features investigated.

Functionally Prioritized Road network – a road classification used by the STA (Sw. Funktionellt Prioriterat Vägnät).

GHG – greenhouse gases

GIS – geographical information system

Global mean sea level – mean level of all oceans on Earth.

IPCC – Intergovernmental Panel on Climate Change, with five published assessment reports:

- FAR – First assessment report
- SAR – Second assessment report
- AR3 – Third assessment report
- AR4 – Fourth assessment report
- AR5 – Fifth assessment report

RCP – Representative Concentration Pathways

Redirection routes – alternate roads used when the functionally prioritized roads are not usable (Sw. omledningsvägnät).

RF – Radiative Forcing

Risk levels – levels of inundation risk divided into long- and short- duration, based on current elevation:

- Long-duration, very high risk: under 0.5 m a. s. l.
- Long-duration, high risk: 0.5 – 1.0 m a. s. l.
- Long-duration, medium risk: 1.0 – 3.0 m a. s. l.
- Long-duration, low risk: over 3.0 m a. s. l.
- Short-duration, very high risk: under 2.5 m a. s. l.
- Short-duration, high risk: 2.5 – 3.0 m a. s. l.
- Short-duration, medium risk: 3.0 – 5.0 m a. s. l.
- Short-duration, low risk: over 5.0 m a. s. l.

STA – Swedish Transport Administration (Sw. Trafikverket)

State-owned roads and railways – roads and railways managed by the STA.

Thermal expansion – increasing volume caused by an increase of temperature, e.g. in oceans.

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1 Introduction

Since the industrial revolution in the mid-19th century, anthropogenic emissions of the greenhouse gases (GHG's) CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide) have continuously increased. A major part of the emitted gases has been absorbed by the oceans and a smaller part by the atmosphere. This increase of GHG in the atmosphere causes global warming which induces several different types of climate change (IPCC 2014b).

Two of the climate changes caused by global warming affect the global mean sea level directly; thermal expansion and melting of the cryosphere (IPCC 2014b). Thermal expansion in the oceans has until now been the major contributor to sea level rise (Chen et al. 2017) due to increased water volume with rising temperatures (Marshak 2015). However, with increasing global surface temperature, melt water contribution to sea level rise increases as the rate of melting is accelerating in all parts of the cryosphere (IPCC 2013).

There are several different projections for future climate change and adherent sea level rise based on different scenarios of GHG emissions. Future climate change can be limited by reducing emissions, but several of the current climate changes would continue in future. One projection being future global mean sea level rise, for which different sources claim different levels but all agree that the sea level will continue increasing both during and after the 21st century (IPCC 2013). A higher sea level will result in the inundation of land and could potentially also affect state-owned roads and railways as well as environmental objects positioned along them.

1.1 The Swedish Transport Administration and climate change adaptation

The Swedish Transport Administration (STA, Sw. Trafikverket) is the authority responsible for long-term planning of the Swedish infrastructure including roads, railways, aviation and shipping. It is also responsible for creating and maintaining the state-owned roads and railways (Trafikverket 2018a).

According to Trafikverket (2018b), the climate change adaptation in Sweden is controlled by several different international contracts and strategies, including the climate change adaptation strategy adopted by the European Union in 2013 (European Union 2013) and the United Nations' Agenda 2030 (Regeringskansliet n.d.).

The Swedish government has assigned the STA the task of ensuring that the transportation system is sustainable on a long-term basis and that the infrastructure is effective for both industry and trade as well as for the public. To ensure that the work carried out is long-term sustainable, the STA incorporates climate change adaptation work in both existing and new infrastructure (Trafikverket 2018b).

For projections of future climate, the Intergovernmental Panel on Climate Change's (IPCC's) Representative Concentration Pathway (RCP) 4.5 is the basis for all climate projections except mean sea level, where RCP 8.5 is used. However, as climate change adaptation is not the only factor, but one of several factors weighted when choosing a level of future climate change for a project, different RCP's could be used for different projects. RCP 8.5 is used for sea level rise as there is a need to be prepared for higher water levels since there is great uncertainty about the magnitude of future sea level rise (Trafikverket 2018b).

To decrease future effects of climate change, the STA uses several tools to map out the potential effects by creating analyses over current and future need as well as of risks associated with every project. The STA adapts existing and planned infrastructure according to these analyses by e.g. increasing the elevation of roads and railways as well as planning alternate routes. Different parts of the state-owned roads and railways have different life spans and while long-lived structures might need to be adapted for future climate change from the first creation, more short-lived structures will be automatically replaced several times before climate change demands it and hence might not need climate change adaptation in the original construction (Trafikverket 2018b).

However, the STA is not only responsible for the condition of the state-owned roads and railways, but also for its side areas, as roads and railways are a part of the landscape. This means that the STA also needs to calculate the risks that future climate change and adherent sea level rise poses to environmental objects positioned in these side areas, including solitary and alley trees, ancient remains and species rich side areas to roads and railways (Trafikverket 2018b).

1.2 Motivation

Geographical information system (GIS) analyses could be used to predict the effects of future sea levels, on e.g. transportation systems (Ebert, Ekstedt & Jarsjö 2016; Eriksson, Ebert & Jarsjö 2018) and road and railway side environmental objects. However, as many ancient remains are located close to water (Arnesten 2015) hydrological overlay GIS analyses could also enable analyses of the effect that future sea levels could have on ancient remains.

Analyses that show the impacts of several possible, future sea levels and highest projected high water level could be used to compose a risk assessment. This could in turn be a useful tool in the planning of preventive actions to protect the state-owned roads and railways and environmental objects on several time horizons.

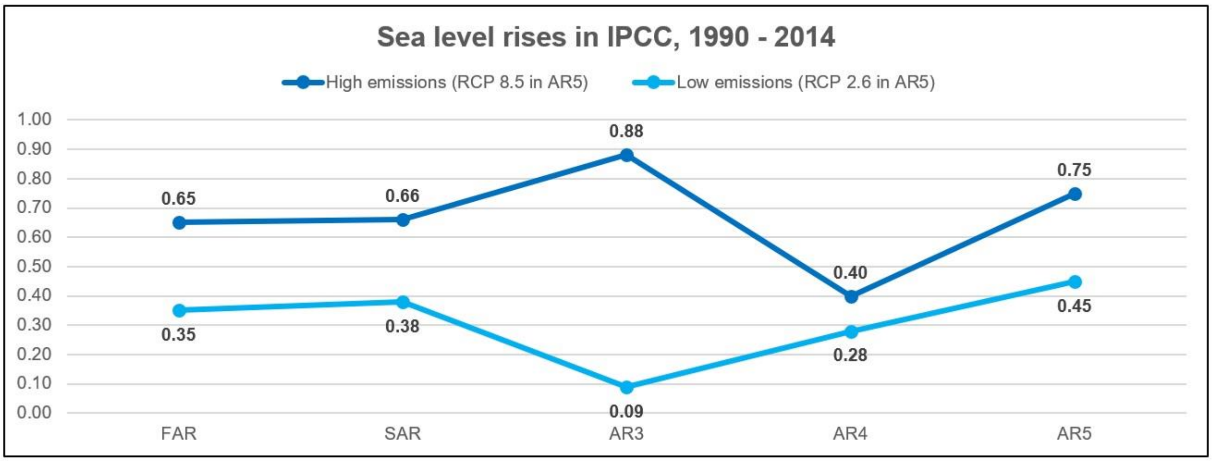

Figure 1. Medians of the low and high emission scenarios (RCP 2.6 and 8.5 in AR5) of sea level rise by 2100 for IPCC's five assessment reports; IPCC First Assessment Report (FAR; Beaumont et al. 1990), IPCC Second Assessment Report (SAR; Alley et al. 1995), IPCC Third Assessment Report (AR3; Watson et al. 2001), IPCC Fourth Assessment Report (AR4; Meehl et al. 2007) and IPCC Fifth Assessment Report (AR5; IPCC 2013).

As is shown in the background section, different studies of sea level rise base future projections on different drivers, depending on the current scientific status in the field (Parris et al. 2012; IPCC 2013; Kopp et al. 2014; Sweet et al. 2017). The study, knowledge and science of climate change and its diversity of drivers is continuously being updated and hence climate projections evolve with further research. An example of this is that the sea level rise projections change between the five assessment reports presented by the IPCC (Beaumont et al. 1990; Alley et al 1995; Watson et al. 2001; Meehl et al. 2007; IPCC 2013). This is shown in figure 1.

Due to this, there is a need to continuously monitor the development within the field of climate change science as well as to adapt analyses and projections of climate change when predicting future sea level rise and impacts. GIS analyses could be used to show the impacts of a range of potential future sea levels that exceed the range of sea level rise that is considered probable in both near and far future. Hence, this thesis will provide impact scenarios for a range of possible future sea levels.

1.3 Objectives

This thesis will analyze a range of potential, future sea levels and evaluate if and when the different levels might occur according to projections of future sea level rise from different sources. The thesis aims at using this range of sea levels to assess the risk that different future sea levels pose to the state-owned roads and railways as well as land and environmental objects. The result of this will produce a risk assessment pointing out where vulnerable state-owned roads, railways and environmental objects are positioned in Scania. The risk assessment will also be a tool for comparing the impacts of different future sea levels.

This thesis is expected to show that several state-owned roads and railways as well as environmental objects and land areas are at risk of future inundation, and hence in need of preventive action.

1.4 Main research question

How will different inundation risk levels caused by a range of different increases in sea level, and a combination of sea level and highest projected high water, affect the state-owned roads and railways as well as environmental objects by increasing the risk of inundation?

To answer this, hydrological analysis of different ocean levels will be used to assess which levels will inundate, and hence affect, the following features:

- State-owned roads, with categories for functionally prioritized road network and redirection routes.
- State-owned railways.
- Environmental objects along the state-owned roads and railways, divided into the following classes:
  - Ancient remains and culturally protected bridges,
  - Solitary trees and alley trees,
  - Species rich side areas to roads and railways,
  - Fauna passages;
    - Water living fauna,
    - Medium sized fauna,
    - Large fauna,
    - Amphibians and reptiles.

1.4.1 Complimentary research questions

To complement the main research question, this thesis will also answer five complementary, statistical investigations:

1. Is there a difference in distribution of inundation risk levels between different environmental objects or between roads and railways?
2. How are different municipalities affected by different risk levels of sea level increase and highest projected high water?
3. Is there a difference in features affected by different risk levels between the different municipalities of Scania?
4. How does the investigated inundation risk levels spatially affect the roads, railways and environmental objects in the municipality with the largest area affected by the analyzed water levels, and the municipality with the largest affected percentage?
5. On which timeframes are different water levels and adherent inundation risk levels likely to occur?

2 Background

2.1 Previous studies

Several studies have investigated past, present and future global mean sea level and sea level rise on a global and/or local scale, e.g. IPCC (2013), IPCC (2014a), IPCC (2014b), Kopp et al. (2014) and Sweet et al. (2017).

In Sweden, some scientific studies have been performed in this subject, for example on the effect of a 2 m sea level rise on land areas, infrastructure and the risk of well salinization on the islands of Öland (Ebert, Ekstedt & Jarsjö 2016) and Gotland (Eriksson, Ebert & Jarsjö 2018). Governmental institutions (e.g. MSB 2012; SGU 2017; SMHI 2018a) have mapped projected sea level rise, predominantly based on IPCC: s fifth assessment report (AR5) (IPCC 2013; IPCC 2014a; IPCC 2014b).

2.2 Literature review

2.2.1 General climate change

Earth constantly receives energy from the Sun in the form of radiation. Some of the light is reflected into space by the atmosphere and the remaining influx of light is absorbed by Earth's surface as thermal energy. Darker surfaces like bare soil have a lower albedo enabling them to keep more of the energy, while lighter surfaces like snow and ice with a high albedo radiates the thermal energy upwards. The thermal energy then either escapes out into space or is absorbed by the GHG in the atmosphere, which include CO_2, CH_4, N_2O, H_2O (water) and O_3 (ozone) (Marshak 2015).

Since the industrial revolution in the mid-19th century, anthropogenic GHG emissions have increased due to growth in both population and economy. These emissions have led to the highest atmospheric concentrations of CO_2, CH_4 and N_2O in at least 800 000 years. Anthropogenic GHG emissions are still increasing, and about half of the anthropogenic CO_2 emissions made between 1750 and 2011 have been made during the last decades, since 1970 (IPCC 2014b).

Increasing emissions also cause the global surface temperature to increase and the three decades of 1980, 1990 and 2000 have with certainty been the warmest 30-year period since at least the 1850's and possibly also for the last 1 400 years. The occurrence and severity of extreme weather events is another factor that has changed since the mid-20th century and e.g. sea level extremes have increased (IPCC 2013; IPCC 2014b).

Climate change during the last decades have impacted anthropogenic and natural systems on a global scale. Both oceans and freshwater resources are affected by an increasing amount of GHG in the atmosphere. This has caused increased melting of cryosphere parts like glaciers and ice sheets as well as thawing permafrost, which causes the groundwater levels and surface water to decrease. These changes in the hydrological cycle decreases the biodiversity of marine and terrestrial species since they are forced to shift activities, migration and spatial distribution and the risk of species extinction is increased (IPCC 2014a).

A melting cryosphere also accelerates the rate of global warming, as lighter surfaces like snow and ice have a higher albedo than darker surfaces. I.e. the more the cryosphere melts, the more energy is absorbed by the surface and the global warming is accelerated. This is one of the reasons for the coldness of ice ages and the warmth of the interglacials. Another explanation for this is that a warmer atmosphere can contain more H_2O which increases the temperature in the atmosphere (Andréasson 2006).

2.2.2 Projections of climate change, except sea level rise

Future climate predictions are based on different scenarios of GHG emissions and adherent radiative forcing (RF). The scenarios range from a lower RF based on decreasing GHG emissions in future to higher RF caused by very high future emissions. Four different levels of future RF were identified and used in the AR5 by IPCC (IPCC 2013; IPCC 2014a; IPCC 2014b). These so-called RCPs are based on the different RF levels by 2100 compared to 1750. RCP 2.6 is based on a RF of 2.6 W/m^2 by 2100, RCP 4.5 on 4.5 W/m^2, RCP 6.0 on 6.0 W/m^2 and RCP 8.5 on 8.5 W/m^2 (IPCC 2013).

The predictions presented for the different future scenarios are linked to the three probability ranges; likely 66 – 100 % probability, very likely 90 – 100 % and virtually certain 99 – 100 % (IPCC 2013). Future GHG emissions depend on several factors including climate policy, adaptation and mitigation as well as socio-economic factors like economy, population growth, technology and lifestyle choices (IPCC 2014b). Currently, the GHG emissions are in line with RCP 8.5 (Hayhoe et al. 2018)

For all RCPs, the global surface temperature is predicted to continue increasing during the 21st century and beyond 2100 for all RCPs but RCP 2.6. Between 2016 and 2035, the global surface temperature is predicted to increase 0.3 to 0.7 °C compared to the temperature of 1985 to 2005 for all RCPs. In the last two decades of the 21st century, the global surface temperature in relation to the same period is projected to increase 2.6 – 4.8 °C for RCP 8.5. Land areas are expected to experience larger increases in surface temperatures than the oceans, and the warming of the Arctic region is likely to be greater than the global mean increase in temperature (IPCC 2013).

If GHG emissions and adherent RF were to decrease or even reverse in future, climate change would still occur as several of the observed changes to the climate system are irreversible on decadal to millennial timescales. Changes like the summer Arctic sea ice disappearance and circulation of monsoons are reversible on a decadal time scale, while the dieback of boreal and tropical forests will take centuries to reverse. However, CH_4 release from clathrate, ice sheet collapse and CO_2 release from permafrost will be irreversible for millennia even if the RF was to be reversed (Collins et al. 2013).

2.2.3 Sea level rise drivers

The global warming that increasing GHG emissions has caused, leads to decreasing mass of the cryosphere due to melting and thermal expansion, i.e. warming oceans. Earth’s oceans absorb 90 % of the heat energy resulting from global warming and the upper part of the oceans warmed 0.11 °C per decade between 1971 and 2010 (IPCC 2014b). The global oceans are predicted to continue warming during the 21st century and the top 100 meters of the oceans are likely to warm between 0.6 °C (RCP 2.6) and 2.0 °C (RCP 8.5) while a level 1 000 meters below the surface is projected to have a temperature increase between 0.3 °C (RCP 2.6) and 0.6 °C (RCP 8.5) (IPCC 2013).

Climate change and adherent global warming causes sea levels to increase due to both thermal expansion and increasing amounts of meltwater from e.g. melting ice caps and glaciers. However, for areas like Northern Europe where inland ice existed 10 000 years ago, sea levels in relation to land also changes due to land subsidence and uplift caused by the post-glacial rebound these areas experience. Tidal variations are another driver of sea level rise, as it causes the sea level to increase and decrease (Marshak 2015).

Global warming also causes changes in the global cryosphere including accelerating loss of mass from the Antarctic and Greenland ice sheets, increased melting of glaciers and permafrost and decreasing snow covers in the Northern Hemisphere. For all RCPs, thermal expansion in warming oceans and melting of several parts of the cryosphere are predicted to continue through the 21st century as the temperature increases. The effects of GHG emissions are not short-term and the global mean surface temperature and the global mean sea level will continue to increase beyond 2100. An increase in surface temperature of just a few degrees compared to pre-industrial levels could cause near total mass loss for the ice sheet of Greenland (IPCC 2014b).

At the end of the 21st century, the following decreases are projected for the cryosphere (IPCC 2013):

- Between 7 % (RCP 2.6) and 25 % (RCP 8.5) for the snow cover area of the Northern Hemisphere.
- From 15-55 % (RCP 2.6) to 35-85 % (RCP 8.5) for the global glacier volume.
- 43 % (RCP 2.6) to 94 % (RCP 8.5) for the summer minimum Artic sea ice extent in September.
- 8 % (RCP 2.6) and 34 % (RCP 8.5) for the winter maximum Arctic sea ice extent in February.
- Between 37 % (RCP 2.6) and 81 % (RCP 8.5) for near surface permafrost.

Thermal expansion and the melting of the cryosphere from these sources in combination contribute to increasing the global mean sea level (IPCC 2014b). In 1993, thermal expansion contributed with 50 % of the increase in global mean sea level, while mass contribution from e.g. melting ice caps and mountain glaciers accounted for the remaining 50 %. By 2014, the contribution from cryosphere mass loss was the major contributor to increasing global sea levels, with 70 % (Chen et al. 2017). During the 21st century, the cryosphere, excluding Antarctica's peripheral glaciers, is predicted to decrease by 15 to 55 % under RCP 2.6 and by 35 to 85 % under RCP 8.5 (IPCC 2013).

Sea level rise is projected to continue past 2100 as both cryosphere melting and thermal expansion are predicted to continue even if the global surface temperature is stabilized at an elevated level in future. At least parts of the mass loss of ice sheets caused by melting is irreversible, hence there is a risk that the Greenland ice sheet will melt completely. If that would happen, it could take up to a million years until the ice sheet recovers (IPCC 2013).

Continued thermal expansion and melting of the cryosphere during the 21st century is projected to cause a continuing increase of the global mean sea level, likely at a rate faster than the one observed between 1971 and 2010 (IPCC 2014b).

2.2.4 Effects of sea level rise

Sea level rise on a global scale will not be uniform, but it is likely that the water level will increase for over 95 % of the global ocean area by 2100 and approximately 70 % of coastlines will be affected by an increase of +/- 20 % of the global mean sea level rise during the 21st century. Increasing sea levels during and after the 21st century leads to increasing risks of coastal flooding, inundation and coastal erosion with different magnitudes for different parts of the world (IPCC 2014a).

Coastal flooding is already affecting Europe, with 102 000 people exposed each year today and an expected cost of €1.25 billion in yearly damages. It is unclear whether current floods are amplified by sea level rise, but as development continues along the shores of Europe, and the risk of coastal flooding increases with rising sea levels, by the end of the 21st century, between 1.52 and 3.65 million people each year are expected to be exposed to coastal flooding and damages are estimated to €93 - €961 billion each year (Vousdoukas et al. 2018).

Inundation of infrastructure, agriculture and industrial land could lead to a decrease in productivity and transportation as well as contamination of land and water from nutrients and other contaminants potentially located within inundated land uses (Ebert, Ekstedt & Jarsjö 2016). Sea level rise could by inundation potentially create new connections between oceans that are separated by land today and turn previously attached land into islands as well as affect the spread of sediments, since the sea level affects the rate of sedimentation (Andréasson 2006).

Future sea level rise poses a risk for the infrastructure, as it will affect both planned and existing parts of the state-owned roads and railways, by e.g. inundation. An increase in global mean sea level has long-term effects, but storms could increase the sea level additionally, causing more severe effects on shorter terms. Both long-duration, slow changes in the climate and short-duration, quick changes have already affected the state-owned roads and railways in Sweden (Trafikverket 2018b).

Climate change has primarily negative effects on the economic development, but some aspects also see a positive development. In Northern Europe, the productions of hydropower and wind energy as well as road accidents are projected to experience a neutral to positive increase by 2050. At the same time, the oceanic transportation cost and time as well as the general energy consumption is predicted to have a positive decrease, while other factors will receive a negative increase, e.g. weather-related rail delays, loss of cultural landscapes and damage to cultural buildings (Kovats et al. 2014).

2.3 Past, present and future sea level rise

The pace of global mean sea level increase was relatively low and stable for two thousand years until the beginning of the 20th century when the rate started to increase. Estimates of past sea level rise show continuously increasing rates of rise during the last century, with the average rise for the entire period of 1901 to 2010 being 1.7 mm/year, while the rate was 2.0 mm/year for the last 40 years of the period and 3.2 mm/year between 1993 and 2010 (IPCC 2013). The rate of global mean sea level increase continues, as NASA's (2018) measurements of the average global mean sea level change between 1993 and 2018 shows a rate of 3.4 +/- 0.4 mm/year.

Parris et al. (2012) base their sea level rise projection on evidence incorporating the importance of ice sheet loss as a main contributor to future increases in sea level. This projection considers ice sheet loss as a greater sea level rise driver than thermal expansion during the 21st century. The projected global mean sea level changes range from a high confidence sea level rise of 0.2 meters by 2100, through medium confidence levels of 0.5 and 1.2 meters to a lower confidence sea level rise of 2.0 meters.

IPCC (2013) estimates that the sea level is likely to have risen 0.52 to 0.98 meters by 2100 according to the high emissions scenario RCP 8.5. As the melting of the cryosphere is projected to continue past 2100, sea level rise projections show an increase of up to 1.0 meter under RCP 2.6 and 1.0 to 3.0 meters under RCP 8.5 by 2300.

Kopp et al. (2014) have calculated sea level rise with probabilities for all four of IPCC's RCPs, using both the natural, non-climatic and long-term drivers of glacial isostatic adjustment, tectonics and compaction of sediments as well as the climate related sea level rise drivers. These include the ice sheets of Greenland, West and East Antarctic, ocean dynamics and surface mass balance. Ocean steric, land water storage and thermal expansion as well as ice caps and glaciers are also included as climatic sea level rise drivers.

The projections of Kopp et al. (2014) are made for the four years of 2050, 2100, 2150 and 2200, and with the three levels of probability presented by IPCC (2013). The sea level rise for each of these years and probabilities are shown in table 1, together with the projected sea level rises by Parris et al. (2012), IPCC (2013) and Sweet et al. (2017).

Table 1. Projected sea level rise from the sources listed in this section, including RCP used for projection and probability or confidence. As some predictions of sea level rise are made in ranges and others with an average value, the sea level rise values in the table are divided into these two formats.

				Sea level rise (m)	
	Source	**RCP**	**Probability/ Confidence**	Range	Average
2050	Kopp et al. (2014)	8.5	Likely	0.24-0.34	-
	Kopp et al. (2014)	8.5	Very likely	0.21-0.38	-
	Kopp et al. (2014)	8.5	Virtually certain	0.16-0.49	-
2100	IPCC (2013)	8.5	Likely	0.52-0.98	-
	Parris et al. (2012)	-	High confidence	-	0.2
	Parris et al. (2012)	-	Medium confidence	0.5-1.2	-
	Parris et al. (2012)	-	Low confidence	-	2.0
	Sweet et al (2017)	8.5	Low confidence	-	2.5
	Kopp et al. (2014)	8.5	Likely	0.62-1.00	-
	Kopp et al. (2014)	8.5	Very likely	0.52-1.21	-
	Kopp et al. (2014)	8.5	Virtually certain	0.39-1.76	-
2150	Kopp et al. (2014)	8.5	Likely	1.00-1.80	-
	Kopp et al. (2014)	8.5	Very likely	0.80-2.30	-
	Kopp et al. (2014)	8.5	Virtually certain	0.60-3.70	-
2200	Kopp et al. (2014)	8.5	Likely	1.30-2.80	-
	Kopp et al. (2014)	8.5	Very likely	1.00-3.70	-
	Kopp et al. (2014)	8.5	Virtually certain	0.60-6.30	-
2300	IPCC (2013)	2.6	Likely	-	1.0
	IPCC (2013)	8.5	Likely	1.0-3.0	-

Sweet et al. (2017) developed a scenario for extreme sea level rise, which uses the methodology of Kopp et al. (2014) and adds the event of extreme ice loss from the Antarctic to the levels of IPCC's RCP 8.5 scenario. This model is based on an Antarctic ice loss model by DeConto & Pollard (2016), and observations made during recent years projects a sea level rise of 2.5 meters by 2100 compared to 2000 (average of 1991-2009). The probability of the scenario is unknown, but the consequences of the sea level rise indicated by this scenario would be high. However, as current GHG emissions are in line with RCP 8.5 (Hayhoe et al. 2018) and sea level rise is predicted to continue past 2100 (IPCC 2013), this model could be worth considering.

Swedish municipalities generally incorporate sea level rise until 2100 in their strategy plans (Ebert, Ekstedt & Jarsjö 2016), e.g. a likely rise of up to 1 meter under RCP 8.5 (IPCC 2013). However, in Scania, the lowest recommended elevation for new residential buildings is a minimum of 3.0 meter above sea level (m a. s. l.), while commercial buildings are recommended to be placed at least 2.5 m a. s. l. (Länsstyrelsen Skåne 2012).

IPCC (2013) states that in 2013 there had been insufficient evidence to support an evaluation of larger increases in global mean sea level during the 21st century compared to the levels presented in AR5. However, other studies include sea level rise projections that are up to twice as large as the projections of AR5 (IPCC 2013). The current available research of the West Antarctic Ice Sheet shows that the Thwaites Glacier and the Amundsen Sea are likely to see changes larger than was previously considered in near future and a complete melt of these would attribute to sea level rise with at least three meters (Scambos et al. 2017).

2.4 Highest projected high water

SMHI (2018b) together with the Swedish Maritime Administration (Sw. Sjöfartsverket) regularly measures the sea level at several stations positioned along the coast of Sweden. For these locations several measurements are available including:

- Average high water level. The mean of the yearly maximum water level for all years the station has been active, measured with the mean sea level as a zero-level.
- Highest observed high water level. The highest water level recorded at the station, measured with the mean sea level as a zero-level.
- Highest projected high water level. A value calculated based on the highest observed high water level and the highest observed net increase in sea level at a storm event, calculated with the mean sea level as a zero-level.

In table 2, these measurements are shown for the seven stations situated within Scania.

Table 2. Measurements of high water levels including average, highest observed and highest projected levels for the seven stations within Scania (SMHI 2018b).

	Average high-water level (m a. s. l.)	**Highest observed high-water level** (m a. s. l.)	**Highest projected high-water level** (m a. s. l.)
Simrishamn	0.83	1.23	1.61
Ystad	0.92	1.69	1.99
Skanör	1.00	1.54	2.00
Klagshamn	0.89	1.46	1.90
Malmö	0.97	1.29	1.78
Barsebäck	0.83	1.59	1.91
Viken	1.16	1.68	2.10

3 Material and method

3.1 Study area - Scania

This project focuses on the southernmost county of Sweden, Scania, which has an area of 11 007 km^2 and a population of 1.34 million people. It has land borders with the counties of Halland, Småland and Blekinge and to three oceans; Kattegat, Oresund and the Baltic sea (Nationalencyklopedin 2018). The STA has two offices in Scania, one in Malmö positioned about 2.5 m a. s. l. and one in Kristianstad positioned approximately 1.3 m b. s. l. (Trafikverket 2018c; Lantmäteriet 2016a). Figure 2 shows an overview of the study area.

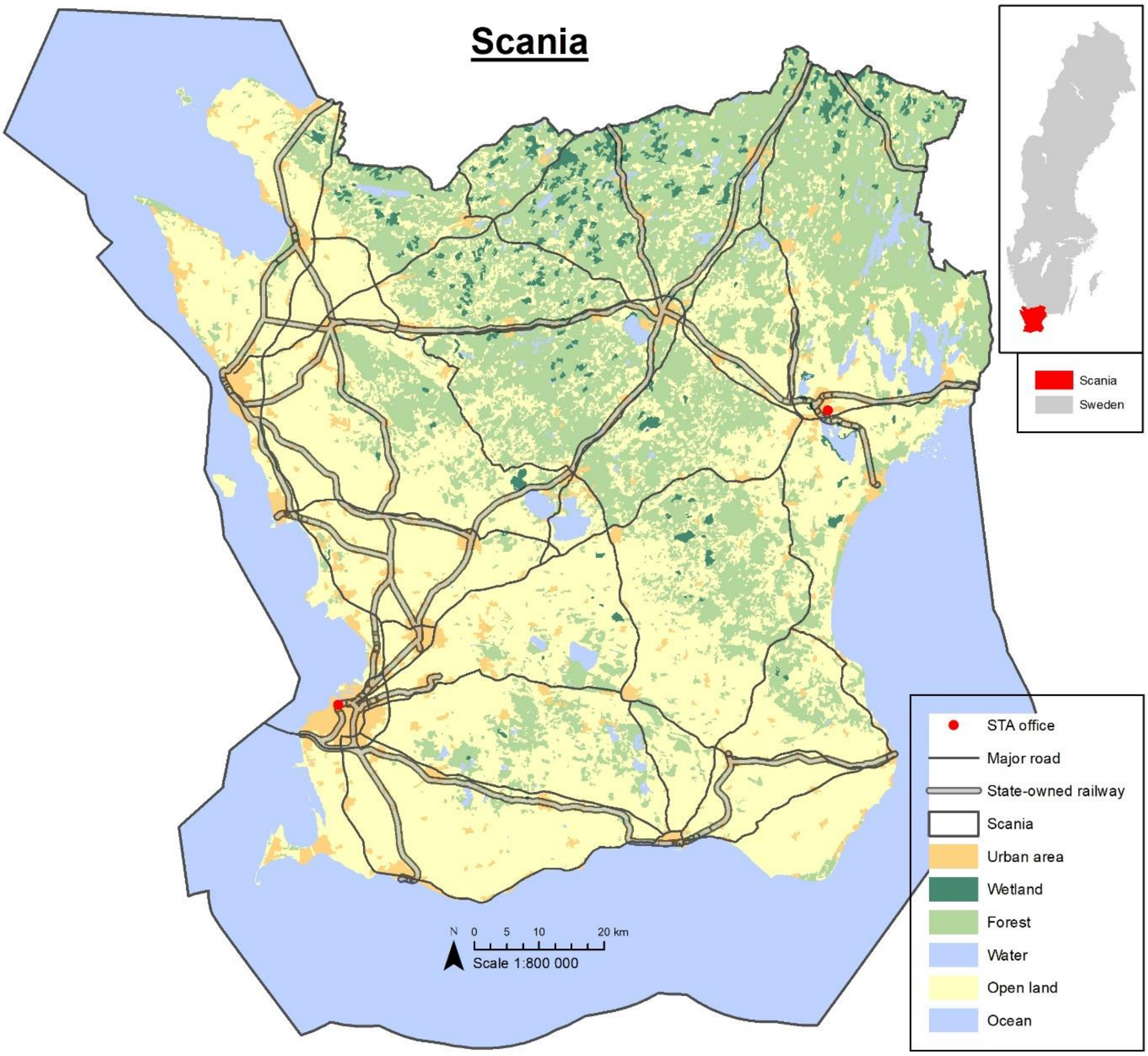

Figure 2. Overview of Scania in relation to the rest of the country. Main roads, land use and the locations of the STA's offices are shown.

Scania mainly contains two different types of landscapes, forests in the central and northeast parts of the county and arable land or pastures in the west, south and east parts. The natural forest is dominated by beech and deciduous trees, but on several locations, these have been replaced by coniferous forests in forestry. A mild climate and a diversity of biomes have made Scania the most species rich county of Sweden for both flora and fauna (Nationalencyklopedin 2018).

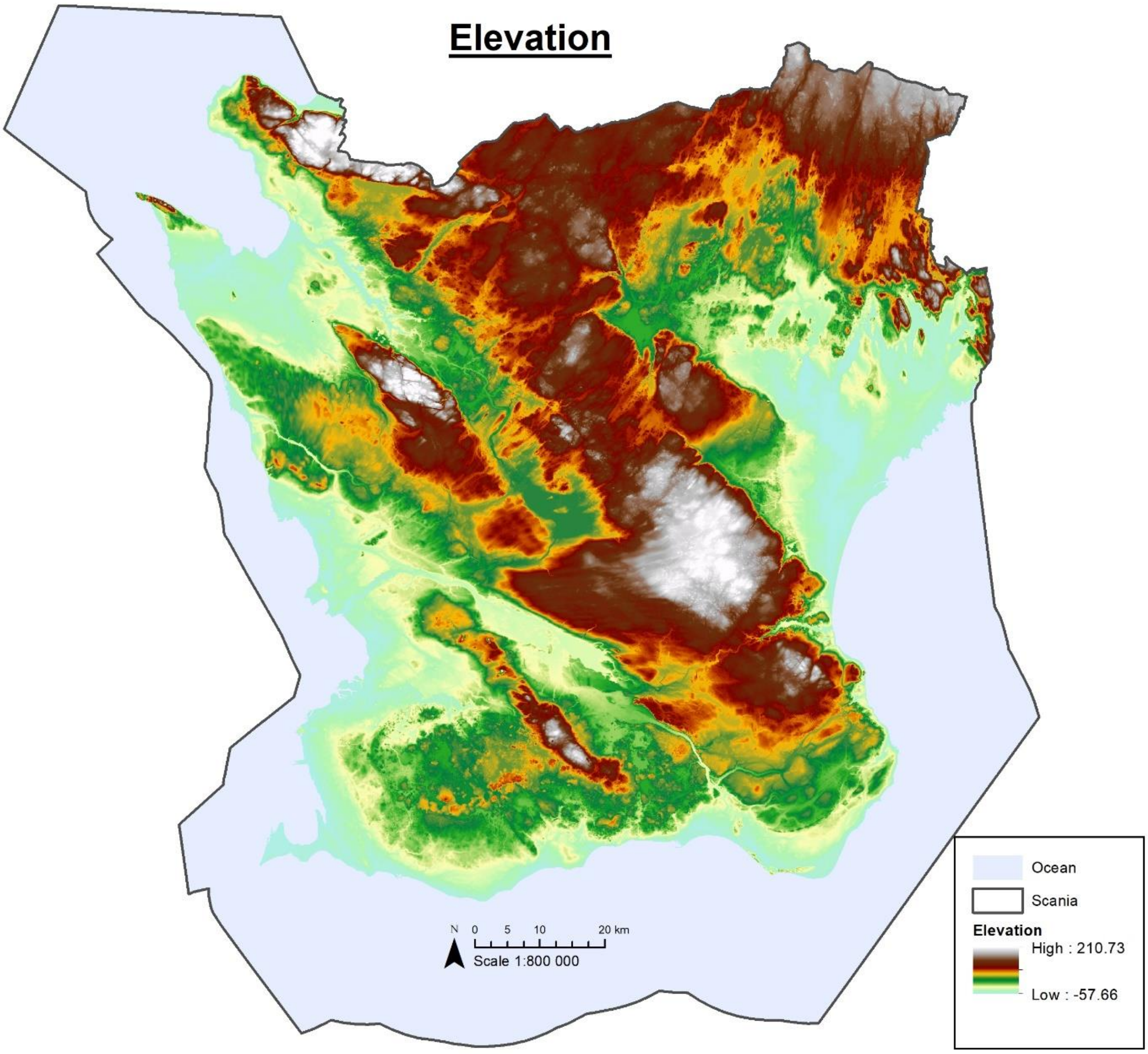

Figure 3. Elevation in Scania.

Scania is divided by the Tornquist-zone, a diagonal border dividing subsiding land in the southwest and bedrock in the northeast. The topology of the county is characterized by this border, which has created an alternating landscape with both low, sedimentary plains and high, bedrock ridges represented by several horsts, stretching through the region from northwest to southeast (Nationalencyklopedin 2018). The highest point in Scania is located on one of these horsts, Söderåsen, with an elevation of 212 m a. s. l., while the lowest, natural point is situated in the northeast part of the county, in the east parts of the city Kristianstad, where the elevation is 2.41 meters below sea level (m b. s. l.) (Region Skåne 2018). The lowest man-made point in Scania is located in a limestone quarry in south of Malmö in the southwest of Scania, where the lowest elevation is 57 m b. s. l., according to the elevation data used in this study. The current elevation of Scania is shown in figure 3.

3.2 Material

3.2.1 Programs

The analyses were conducted using two different computer programs. GIS analyses and visualization of spatial results were performed in ESRI's ArcMap, while Microsoft Excel was used for the statistical analyses and visualization of results in tables and charts.

3.2.2 Data

The spatial data used for the analysis was retrieved from three different sources; the Swedish Land Survey Authority (Sw. Lantmäteriet), the STA and the Swedish Institute of Meteorology and Hydrology (SMHI). The data types are listed according to source below:

The Swedish Land Survey Authority:

- GSD-Elevation data, grid 50+ nh. Elevation rasters with a 50 meter resolution, for calculating spatial extent of different sea levels (Lantmäteriet 2016a).
- GSD-General Map, vector format used as background for maps and to extract municipality borders as polygons (Lantmäteriet 2016b).

SMHI:

- Highest projected high water, statistical data showing calculated levels of high water above mean sea level, without probability (SMHI 2018b).

STA:

- STA’s offices in Scania (Trafikverket 2018c) were included in some of the visualizations, but they are not a part of the analyses.
- State-owned roads in Scania, with categories for functionally prioritized road network and redirection routes (Trafikverket 2018d; Trafikverket 2018e), lines.
- State-owned railways in Scania (Trafikverket 2016), lines.
- Environmental objects along the state-owned roads and railways in the study area (Trafikverket 2018f). No culturally protected bridges and no needs of new fauna passages for amphibians and reptiles are located within Scania, hence neither of these two environmental objects are included in further analysis. Below the included environmental objects are listed:
    - Alley trees, lines.
    - Ancient remains, points.
    - Existing fauna passages for amphibians and reptiles, lines.
    - Fauna passages for large fauna, points.
    - Fauna passages for medium sized fauna, both existing and needed passages, points.
    - Fauna passages for water living fauna, both existing and needed passages, points.
    - Solitary trees, points.
    - Species rich side areas to state-owned railways, polygons.
    - Species rich side areas to state-owned roads, lines.

3.3 Method

The methodology planned for answering the research questions includes three parts; a primary literature review to use for selection and evaluation of different future sea levels. The second part consists of the GIS analyses while statistical analyses make up the third part.

3.3.1 Determining sea levels and risk levels

The sea levels used in the analyses where determined based on a literature review. As the STA uses RCP 8.5 for sea level rise projections (Trafikverket 2018b) and current GHG emissions are in line with this RCP (Hayhoe et al. 2018), this was used for the selection.

Projections (table 1) of likely sea level rise at RCP 8.5 ranges from 0.5-1.0 meters by 2100 (IPCC 2013; Kopp et al. 2014) to about 3.0 meters by 2200 (Kopp et al. 2014) or by 2300 (IPCC 2013), while SMHI (2018b) calculates a highest projected high water of about 1.9 m a. s. l.. Due to this, the analysis was performed on sea levels ranging from 0.5 to 5.0 m a. s. l., with a 0.5-meter interval, i.e. ten different elevations above the current sea level.

The levels of inundation risk were created from these analyzed sea levels. As increasing sea levels is a risk with a longer duration and highest projected high water a more short-duration risk, the risk assessment was divided into two parts, one solely focusing on sea levels and one combining this with highest projected high water. Both the long-duration risks that sea level rise cause with an increasing mean sea level and the short-duration risks caused by sea level in combination with highest projected water were divided into four risk levels each.

The four risk levels that both short- and long-duration risks were divided into was very high, high, medium and low risk of inundation. These levels are defined in appendix A.

3.3.2 GIS analyses

The GSD-Elevation data was reclassified into eleven ranges of sea level increase, based on determined levels to analyze from the first step. The ranges each consists of a 0.5 m a. s. l. increase, with the lowest range being below 0.5 m and the highest above 5 m.

From the ranges of reclassified elevation data, a polygon for each of the determined inundation risk levels was extracted, resulting in eight polygons. An overlay analysis was then performed to divide the four road and railway features as well as the eleven environmental objects from the STA into the eight risk levels, four each at short- and long-duration. Point features were divided through select by location, while line and polygon features were intersected with the risk levels.

To enable analyses of increasing sea level and highest projected high water on a municipal level, the reclassified elevation data and the determined risk levels of inundation were intersected with the 33 municipalities in Scania. Any municipality located above 5 m a. s. l. was excluded from further analysis, as this elevation is the upper border of the analyzed increases in sea level.

The 15 analyzed features from the STA were clipped with each of the included municipalities, i.e. those affected by an increase in sea level below 5.0 m a. s. l., to enable analyses on a municipal level. The last step of the GIS analyses was the visualizations presented in the results below.

3.3.3 Statistical analyses

Values from the GIS analyses were exported into Excel to enable further statistical analysis as well as visualizations in tables and charts for the main and complimentary research questions:

- How will different inundation risk levels caused by a range of different increases in sea level, and a combination of sea level and highest projected high water affect the state-owned roads and railways as well as environmental objects by increasing the risk of inundation?

1. Is there a difference in distribution of inundation risk levels between different environmental objects or between roads and railways?
2. How are different municipalities affected by different risk levels of sea level increase and highest projected high water?
3. Is there a difference in features affected by different risk levels between the different municipalities of Scania?
4. How does the investigated inundation risk levels spatially affect the roads, railways and environmental objects in the municipality with the largest area affected by the analyzed water levels, and the municipality with the largest affected percentage?
5. On which timeframes are different water levels and adherent inundation risk levels likely to occur?

The statistics for the main research question as well as the first complimentary question were calculated through the percentage of each investigated feature within the different risk levels. For polygons and lines, the total area or total length per risk level was calculated and for point data, the number of points per risk level was summarized.

For the second question, the percental areal distribution of the different risk levels was calculated for each of the included municipalities. The third complimentary question was calculated in a similar manor, but for this question the percental distribution of the road and railway features as well as the environmental objects were calculated for each municipality.

The values from the second question were also used to select the two detailed studied municipalities in the fourth complimentary question, as well as to grade the effects of the modelled increases in sea level between the municipalities.

The fifth question was answered by dividing the projections of sea level rise (table 1) into different likely time spans.

4 Results

4.1 Effects of different sea levels

The ten analyzed sea levels each cover between 0.33 and 0.53 % of the total area of Scania, while 95.79 % of the county is unaffected. The spatial distribution of the different levels is presented in figure 4, while the percentage of Scania's total area that is covered by each of the analyzed sea levels are shown in figure 5.

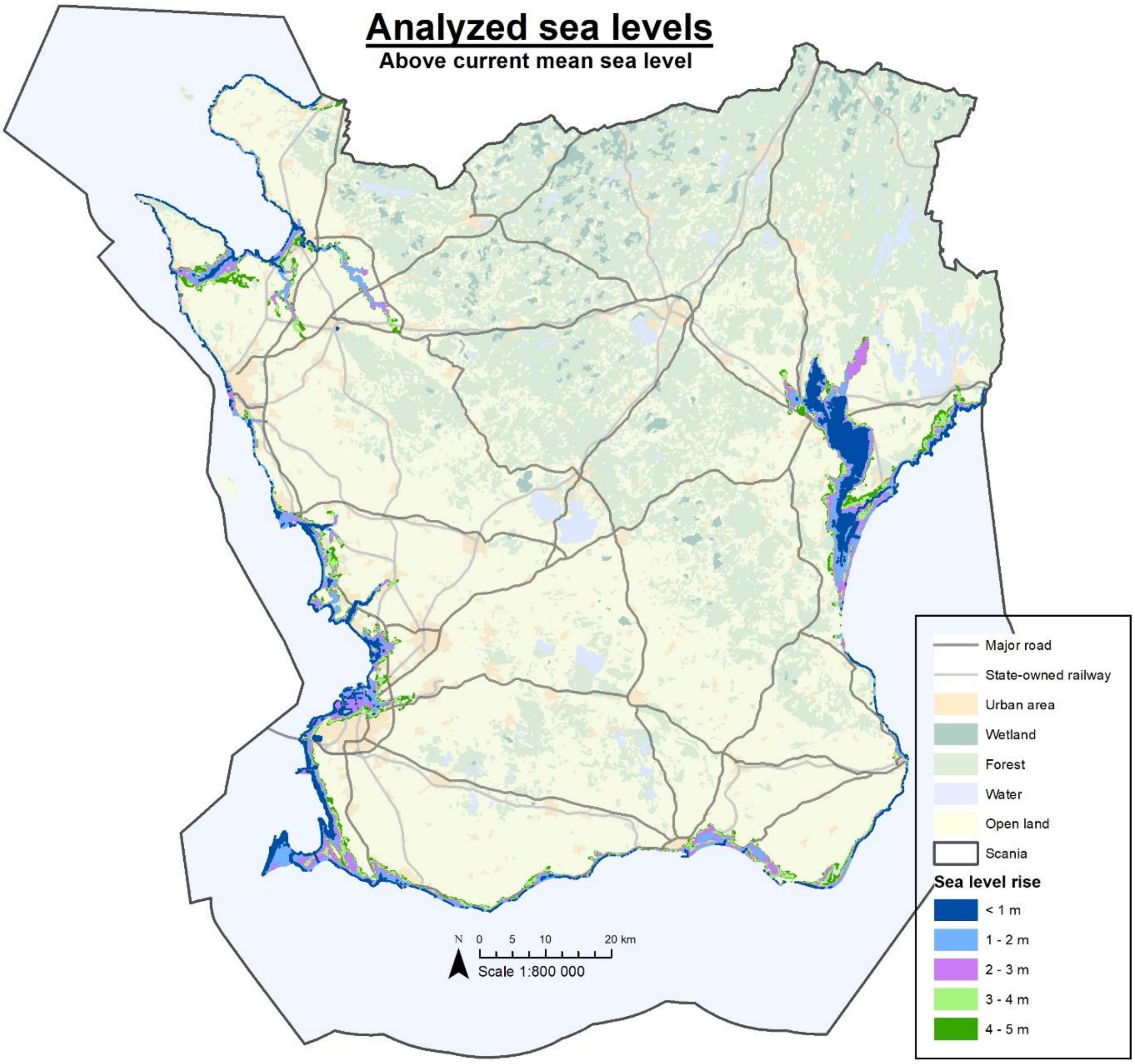

Figure 4. Land affected by analyzed sea levels in Scania in relation to current sea level.

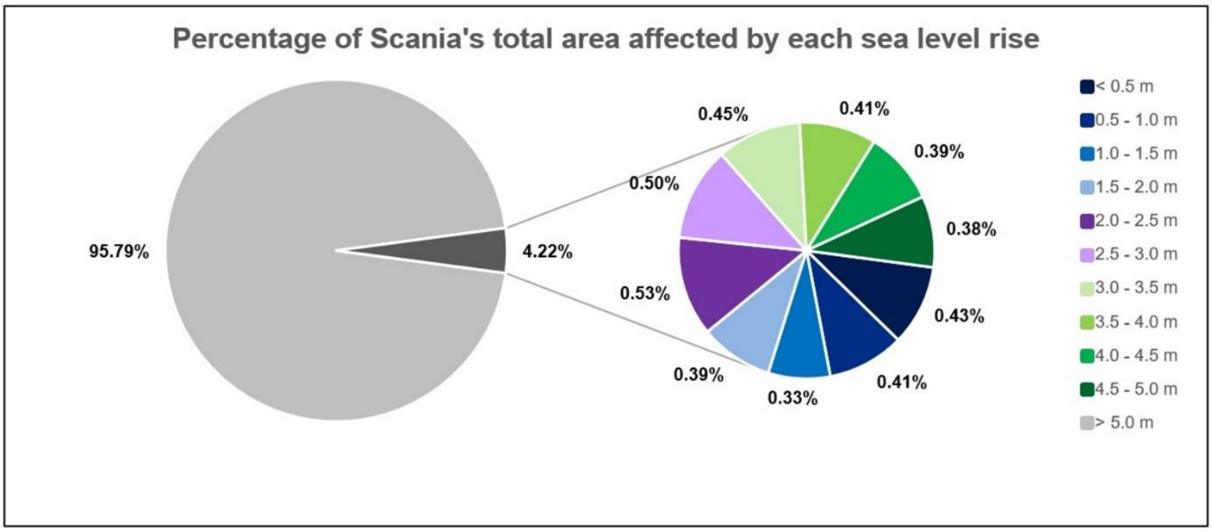

Figure 5. Percentage of the total area of Scania affected by the analyzed sea levels. In the left part of the chart, the sum of the investigated sea levels' percentages is shown in relation to the share of Scania positioned at an elevation not affected by the analyzed water levels. To the right, the share affected by each water level is shown.

4.1.1 Effects of different sea levels – long-duration

The effect of the analyzed long-duration changes in sea level, i.e. the new mean sea level in future, differs both between the four risk levels and between features. As the long-duration, low risk level (over 3 meters) contains all areas at low risk of future increases in sea level, a high percentage for the long-duration, low risk level indicates that a feature only has smaller percentages within the medium, high or very high risk levels, while a lower low risk level indicates that larger parts of the feature are at a medium, high or very high risk of inundation.

For long-duration risks, species rich side areas to railways is the feature that has both the maximum percentage within the medium risk level and the minimum in the low risk level of the environmental objects. Its share in the low risk level is about three quarters and it has approximately one quarter within the medium risk level, leaving the high and very high risk levels with only minor shares, as shown in table 3.

Species rich side areas to roads as well as existing and needed fauna passages for medium sized fauna also have lower percentages within the low risk level, as only 83.70 to 88.80 % of them are located within this level. Among these features, species rich side areas to roads and needed fauna passages for medium sized fauna have large shares for the medium risk level and small percentages for both the high and the very high risk levels. Existing fauna passages for medium sized fauna has the highest percentage within the high and the very high risk levels of all environmental objects, which together are almost as big as the medium risk level.

Table 3. The upper part of the table shows the percentage of each environmental object in Scania affected by the four long-duration risk levels caused by increasing sea levels, with values sorted from smallest to largest percentage within the low risk level. The lower part of the table shows maximum, minimum and average percentage for each risk level.

Risk level / **Feature**	Very high (%)	High (%)	Medium (%)	Low (%)	Cumulative: Very high, high, medium (%)
Species rich side area to railways	0.16	0.06	25.50	74.27	25.72
Species rich side area to roads	0.35	0.28	15.67	83.70	16.30
Existing fauna passages for medium sized fauna	1.72	5.17	8.62	84.48	15.51
Needed fauna passages for medium sized fauna	1.60	0.80	8.80	88.80	11.20
Fauna passages for large fauna	0.00	0.00	3.08	96.92	3.08
Alley trees	0.00	0.02	2.45	97.53	2.47
Ancient remains	0.00	0.17	0.67	99.17	0.84
Solitary trees	0.00	0.00	0.42	99.58	0.42
Needed fauna passages for water living fauna	0.00	0.00	0.00	100.00	0.00
Existing fauna passages for amphibians and reptiles	0.00	0.00	0.00	100.00	0.00
Existing fauna passages for water living fauna	0.00	0.00	0.00	100.00	0.00
Maximum	1.72	5.17	25.50	100.00	25.72
Minimum	0.00	0.00	0.00	74.27	0.00
Average	0.35	0.59	5.93	93.13	6.87

Of the remaining six features in table 3, three are positioned slightly above the average percentage for the low risk level with 93.13 % and have lower shares for the other risk levels than the averages 5.93, 0.59 and 0.35 %. The last three features are solely located within the low risk level, making up both the maximum share for the low risk level and the minimum for the medium, high and very high risk levels; existing fauna passages for amphibians and reptiles as well as both existing and needed fauna passages for water living fauna.

Table 4. Percentage of state-owned roads and railways as well as functionally prioritized roads and redirection routes in Scania within each of the four long-duration risk levels of increasing sea levels. The lowest row shows the difference in percentage between state-owned roads and railways for the four long-duration risk levels.

Risk level / **Feature**	Very high (%)	High (%)	Medium (%)	Low (%)	Cumulative: Very high, high, medium (%)
Railways	0.10	0.09	10.83	88.99	11.02
Redirection routes	0.55	0.11	2.64	96.70	3.30
Functionally prioritized roads	0.17	0.04	2.34	97.50	2.55
Roads	0.10	0.03	1.16	98.72	1.29
Difference Railway - Road	0.00	0.06	9.67	9.73	9.73

State-owned railways have the lowest shares in the low risk level at 88.99 %, of the four, analyzed road and railway features, with 10.83 % in the medium risk level and minor shares in the high and very high risk levels, as is shown in table 4. Roads, functionally prioritized roads and redirection routes on the other hand have higher percentages within the low risk levels of between 96.70 and 98.72 %, with shares in the medium risk level ranging between 1.16 and 2.64 %, percentages in the high risk level of 0.03 and 0.11 % as well as shares in the very high risk level from 0.10 to 0.55 %. When comparing state-owned roads and railways, the difference is approximately 10 % between both the low and the medium risk levels of the two features, while the high risk level only differs slightly, and the very high risk level is the same for both.

The big difference in impact between the long-duration medium and low risk levels indicates that a sea level rise of more than 3 meters will have a substantial impact on state-owned roads and railways. However, as the increase between the high and medium risk levels for railways is also substantial, a sea level rise of over 1 m could have great effects on railways in Scania.

4.1.2 Effects of sea levels and highest projected high water – short-duration

The short-duration, low risk level for shorter term increases in sea level, caused by a combination of rising sea level and highest projected high water, i.e. a rare occurrence of extreme storm levels, contains all land and all features that are at low risk of inundation as they are positioned more than five m a. s. l.. A high percentage within the short-duration, low risk level indicates that a smaller part of a feature is located within medium, high or very high risk of inundation, and vice versa a low share within the low risk level indicates that larger parts are located within the other short-duration risk levels.

Table 5. The upper part of the table shows the percentage of each environmental object in Scania affected by the four short-duration risk levels caused by increases in sea level, with values sorted from smallest to largest percentage in the low risk level. The lower part of the table shows maximum, minimum and average percentage for each risk level.

Risk level **Feature**	Very high (%)	High (%)	Medium (%)	Low (%)	Cumulative: Very high, high, medium (%)
Species rich side area to railways	11.65	14.07	10.75	63.52	36.47
Species rich side area to roads	10.97	9.92	12.50	66.61	33.39
Existing fauna passages for medium sized fauna	12.07	3.45	1.72	82.76	17.24
Needed fauna passages for medium sized fauna	9.60	1.60	5.60	83.20	16.80
Alley trees	1.67	0.80	4.28	93.25	6.75
Solitary trees	0.21	0.21	4.32	95.26	4.74
Fauna passages for large fauna	1.54	1.54	1.03	95.90	4.11
Needed fauna passages for water living fauna	0.00	0.00	2.27	97.73	2.27
Ancient remains	0.67	0.17	1.33	97.83	2.17
Existing fauna passages for amphibians and reptiles	0.00	0.00	0.00	100.00	0.00
Existing fauna passages for water living fauna	0.00	0.00	0.00	100.00	0.00
Maximum	12.07	14.07	12.50	100.00	36.47
Minimum	0.00	0.00	0.00	63.52	0.00
Mean	4.40	2.89	3.98	88.73	11.27

For shorter-duration increases in sea level shown in table 5, species rich side areas to railways and roads are at the largest risk of inundation, as they have the lowest percentage within the low risk level of the environmental objects in Scania. The percentage in the low risk level of species rich side areas to railways and roads is approximately two-thirds each, while the shares in the other risk levels differs between the two features.

Of all environmental objects, species rich side areas to railways has the lowest share in the low risk level at 63.52 % and the highest within the high risk level at 14.07 %, while the percentages within medium and very high risk is slightly lower at 10.75 % and 11.65 % respectively. Species rich side areas to roads, on the other hand, has the highest percentage for the medium risk level at 12.50 %, and lower shares for the high and very high risk levels at 9.92 % and 10.97 %, respectively.

After species rich side areas to railways and roads, existing and needed fauna passages for medium sized fauna have the highest shares for the low risk level at 82.76 and 83.20 %. The percentages within the medium and high risk levels differs between the two features, with existing fauna passages for medium sized fauna having a lower medium risk level of 1.72 % and a higher high risk level at 3.45 % while needed fauna passages for medium sized fauna has a higher medium risk level of 5.60 % and a lower high risk level of 1.60 %. However, for both existing and needed fauna passages for medium sized fauna, the share within the very high risk level is the largest percentage besides the low risk level, as the very high risk level makes up 12.07 % and 9.60 % respectively for these two objects.

Of the remaining seven features in table 5, two features have the maximum share for the low risk level of 100.00 %, existing fauna passages for both water living fauna as well as amphibians and reptiles. The last five features have percentages for the low risk level between 93.25 and 97.83 % with shares within the medium risk level ranging from 1.03 to 4.32 % and smaller parts within the high and the very high risk levels which range from 0.00 to 1.54 % for the high risk level and 0.00 to 1.67 % for the very high risk level.

Table 6. Percentage of state-owned roads and railways as well as functionally prioritized roads and redirection routes in Scania within each of the four short-duration risk levels of increasing sea level. The lowest row shows the difference in percentage between state-owned roads and railways for the four short-duration risk levels.

Risk level / **Feature**	Very high (%)	High (%)	Medium (%)	Low (%)	Cumulative: Very high, high, medium (%)
Railways	4.55	6.46	5.73	83.26	16.74
Redirection routes	2.18	1.12	3.72	92.99	7.02
Functionally prioritized roads	1.67	0.82	2.53	94.97	5.02
Roads	0.84	0.44	1.73	96.98	3.01
Difference Railway - Road	3.71	6.02	4.00	13.72	13.73

State-owned railways have the lowest percentage within the low risk level at 83.26 %, of the four, analyzed road and railway features shown in table 6. The shares within the medium, high and very high risk levels of railways range from 4.55 to 6.46 %, while the three road features have a range of 0.44 – 3.72 % for these three risk levels and shares between 92.99 to 96.98 % for the low risk level each. When comparing the risk levels of state-owned railways and roads directly, the difference between the more affected railways and the less affected roads become more apparent. The biggest difference is found for the share in the low risk level where the two features are 13.72 % apart, while the differences between the shares in the medium, high and very high risk levels differs at 4.00, 6.02 and 3.71 % each.

4.1.3 Comparison of short- and long-duration inundation risk

The order of affected percentage for the low risk levels of the analyzed environmental objects is rather similar between the long-duration risk level shown in table 3 and the short-duration risk level shown in table 5. The four most affected and the two least affected are the same features and in the same order in both tables; species rich side areas to roads and railways as well as existing and needed fauna passages for medium sized fauna. However, the rest of both tables do not share the same similarity, as none of the remaining features are in the same position in the two tables.

When comparing the statistics over the short- and long-duration risk levels for environmental objects it is apparent that both the maximum and the mean of the short-duration very high, high and low risk levels are higher than their counterparts among the long-duration risk levels. However, the medium risk level has a higher share for both maximum and mean in the long-duration medium risk level than the short-duration equivalent.

The four road and railway features; state-owned railways and roads, redirection routes and functionally prioritized roads, are ranked in the same order for both the long-duration risk levels in table 4 and the short-duration risks in table 6. However, when directly comparing the risk levels of both short- and long-duration risks for the railways and roads, railways are at higher risk of being affected at both the permanent, long-duration sea level rise, i.e. the new mean sea level, and the extreme, short-duration storm sea level, i.e. the long-duration sea level rise and the highest projected high water.

Environmental objects are generally more affected by both the long- and the short-duration risk levels, as their means for percentage within both the short- and the long-duration low risk levels, of 74.27 % (table 3) and 63.52 % (table 5) respectively, are lower than shares within these risk levels for all four road and railway features, where the percentage within the long-duration, low risk level ranges from 88.99 to 98.72 % (table 4) and the share within the short-duration, low risk level from 83.26 to 96.98 % (table 6).

4.2 Risks on a municipal level

As is shown in figure 6, 21 of Scania's 33 municipalities are affected by an increasing sea level of up to five meters, while the remaining 12 are positioned at higher elevation and hence not affected by the sea levels analyzed within this thesis. The 21 included municipalities and the lowest sea level affecting each of them are shown in table 7 together with the 12 municipalities that are not included in the analysis.

Table 7. The 21 municipalities included in analysis on a municipal level are shown to the left together with the lowest analyzed sea levels in each of the municipalities. To the right, the 12 municipalities excluded municipalities are shown.

Included municipalities	Lowest sea level increase
Bromölla	< 0.5 m
Burlöv	< 0.5 m
Båstad	< 0.5 m
Helsingborg	< 0.5 m
Höganäs	< 0.5 m
Kristianstad	< 0.5 m
Kävlinge	< 0.5 m
Landskrona	< 0.5 m
Lomma	< 0.5 m
Malmö	< 0.5 m
Simrishamn	< 0.5 m
Skurup	< 0.5 m
Trelleborg	< 0.5 m
Vellinge	< 0.5 m
Ystad	< 0.5 m
Åstorp	< 0.5 m
Ängelholm	< 0.5 m
Klippan	1 - 1.5 m
Staffanstorp	2 - 2.5 m
Svalöv	2 - 2.5 m
Lund	3 - 3.5 m

Excluded municipalities
Bjuv
Eslöv
Hässleholm
Hörby
Höör
Osby
Perstorp
Sjöbo
Svedala
Tomelilla
Örkelljunga
Östra Göinge

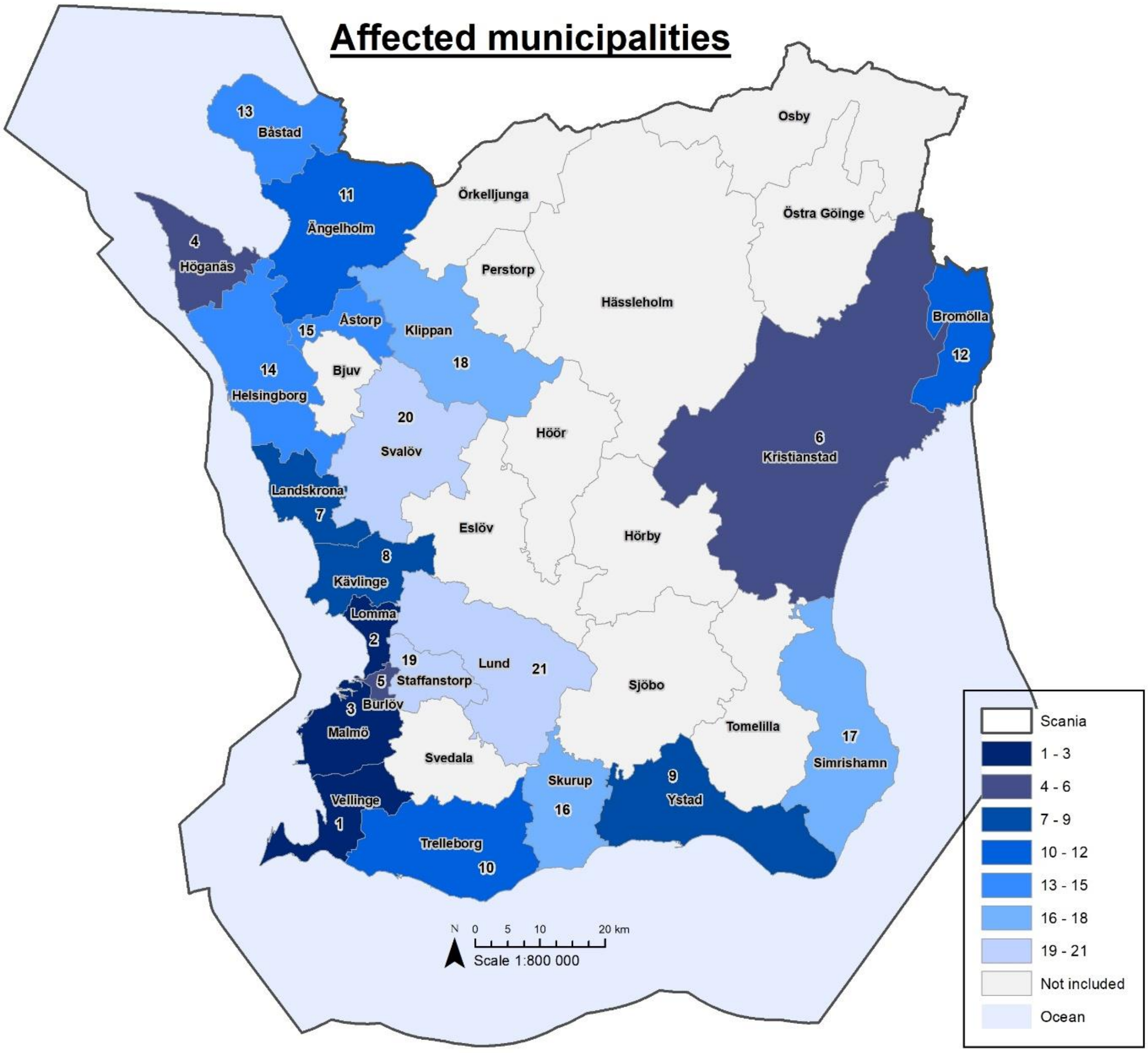

Figure 6. The cumulative effect of the very high, high and medium risk levels for both short- and long-duration sea level rise. The municipality with the largest effect has a value of 1, and the municipality with the lowest 21. The municipalities are grouped three by three for cartographic purposes, but they are still ranked individually.

The percentage of each municipality that is affected by each of the analyzed risk levels extent and severity differs between different parts of Scania. The municipalities most affected by the analyzed sea levels are all focused in the southwestern part of the county, while the remaining affected municipalities are spread along the coast of Scania.

The effect is in this regard the average percentage of a municipality’s area affected by an accumulation of the very high, high and medium risk levels for both short- and long-duration sea levels. The municipality with the lowest average is considered at highest risk, as a low share within the low risk level indicates a higher share within the medium, high and very high risk levels. The average for all municipalities is shown in figure 6, where the municipality at highest risk has the value 1 and the one with the lowest risk 21. The percentage of each municipality's area affected by each of the analyzed risk levels, as well as a cumulation of the very high, high and medium risk levels, are shown in appendix B.

In the 21 municipalities where the effect of increasing sea levels was analyzed, the average percentage of environmental objects as well as road and railway features affected by each of the four long-duration risk levels and the four short-duration levels were calculated and analyzed separately. As the low risk levels for short- and long-duration respectively contains all features that are not located within the other three risk levels, the percentages within the low risk levels were calculated, but not visualized on a municipal level. The percentages of each feature per municipality affected by each of the eight risk levels is shown in appendix C, tables C1 to C14. However, as existing fauna passages for water living fauna is only found in locations positioned above 5 m a. s. l., this environmental object is not shown in an appendix.

The average percentage of both environmental objects and road and railway features affected by one or more risk levels within a municipality were divided into seven groups for visualization. The six lowest groups contain 6 % each i.e. the lowest group contains average percentages between 0 and 6, while the highest group contains all percentages above 36 %.

4.2.1 Risks on a municipal level – long-duration

For environmental objects, the average percentage of affected features per municipality within both the very high and high risk levels are in the lowest group, 0 – 6 %, for all investigated municipalities, except one in the northwest for the very high risk, where the average is 6 – 12 %, as shown in appendix D, figures D1 and D2. However, higher averages are found for the long-duration, medium risk level, as figure D3, appendix D, shows that only about half of the municipalities have averages of 0 – 6 % for this risk level. Of the remaining municipalities, three have averages of 6 – 12 %, two of 18 – 24 % and another three of 30 – 36 %.

In figure 7, the average percentages of environmental objects affected by the long-duration very high, high and medium risk levels are accumulated on municipal level, i.e. this figure shows the potential effects of an increase in sea level up to 3.0 meters. The result of this accumulation is similar to the effects of the medium risk level shown in figure D3, appendix D, except for three municipalities where the average percentage falls within a higher group for the accumulation compared to only the medium risk level. In one of these municipalities almost half of the environmental objects are affected by the accumulated risk levels.

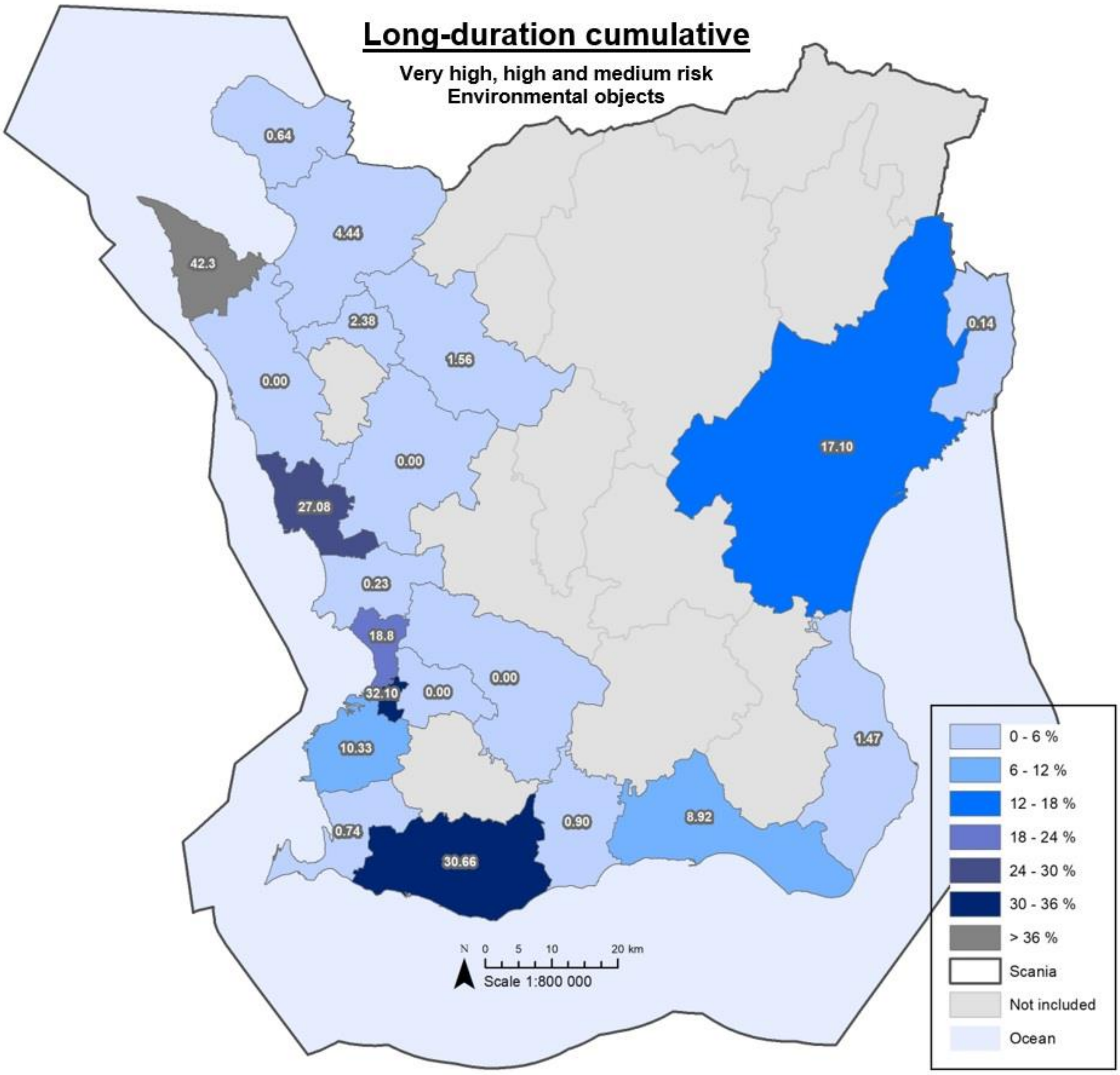

Figure 7. Cumulative map showing the average percentage of environmental objects positioned within the long-duration very high, high and medium risk levels, i.e. below 3.0 m a. s. l. Light blue indicates lower percentages while dark blue indicates higher.

The average percentages of road and railway features affected on a municipal level by each of the three long-duration risk levels show a similar pattern to environmental objects. The averages within both the very high and high risk levels shown in figures E1 and E2, appendix E, are between 0 and 6 % for all municipalities, while there is a larger difference for the shares in the medium risk level, as is shown in figure E3, appendix E. About half of the municipalities have averages of 0 – 6 % for the long-duration medium risk level, while seven municipalities have 6 – 12 % and an average of 12 – 18 % and 18 – 24 % is found for one municipality each.

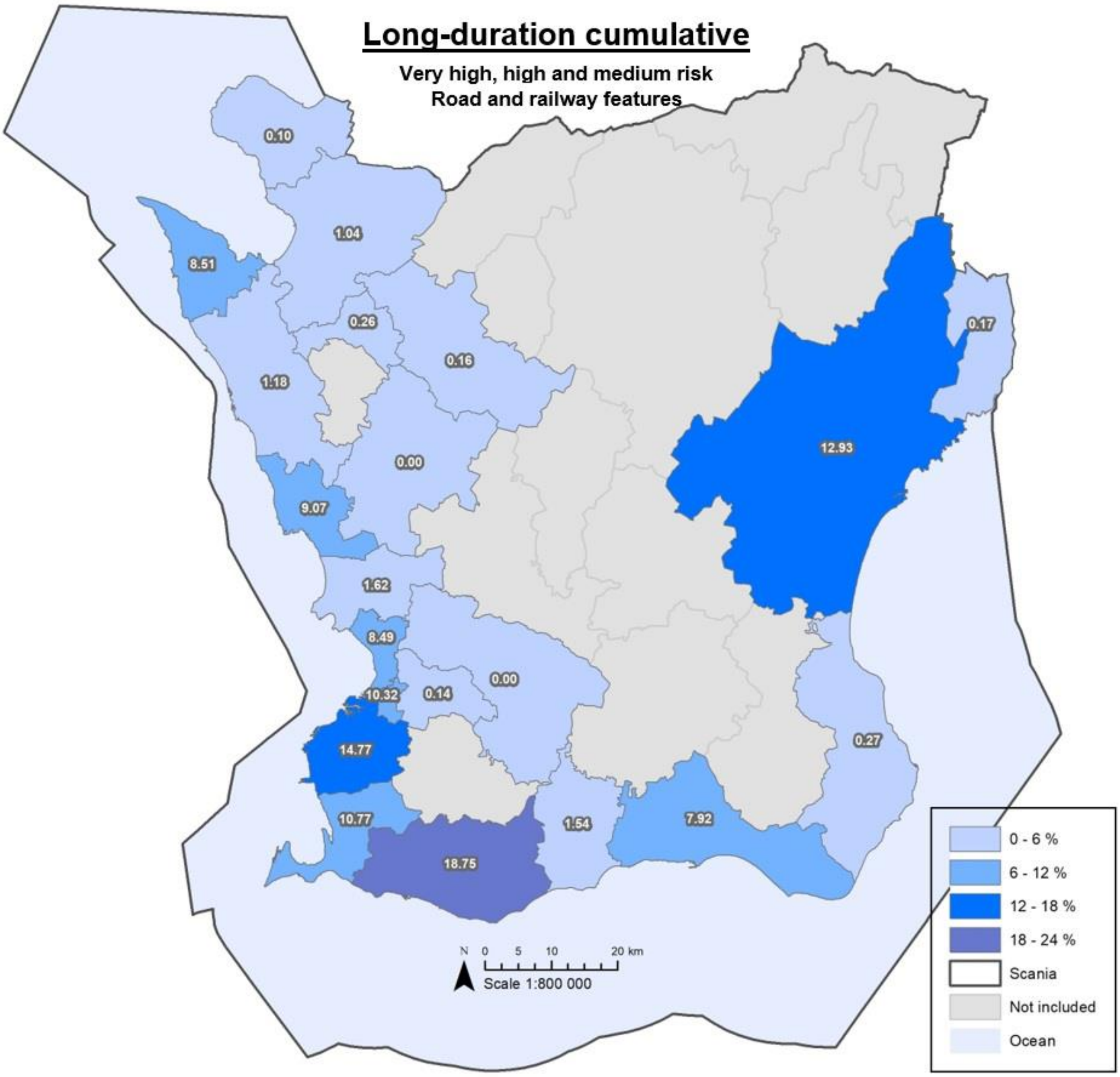

Figure 8. Cumulative map showing the average percentage of road and railway features positioned within the long-duration very high, high and medium risk levels, i.e. below 3.0 m a. s. l. Light blue indicates lower percentages while dark blue indicates higher.

Road and railway features affected by an accumulation of the long-duration very high, high and medium risk levels on municipal level are shown in figure 8, i.e. this figure shows the potential effects of an increase of sea level up to 3.0 meters. This cumulation shows similar results to the affected average percentages of the medium risk level shown in figure E3, appendix E, except for two municipalities that in the accumulation gets a higher percentage and falls within a higher group compared to the medium risk level.

4.2.2 Risks on a municipal level – short-duration

The environmental objects in about half of the investigated municipalities have an average percentage of 0 – 6 % within the short-duration, very high risk level. The average is between 6 and 12 % for three municipalities, while one has 12 – 18 %, two 24 – 30 % and the last one 30 – 36 %, which is shown in appendix F, figure F1.

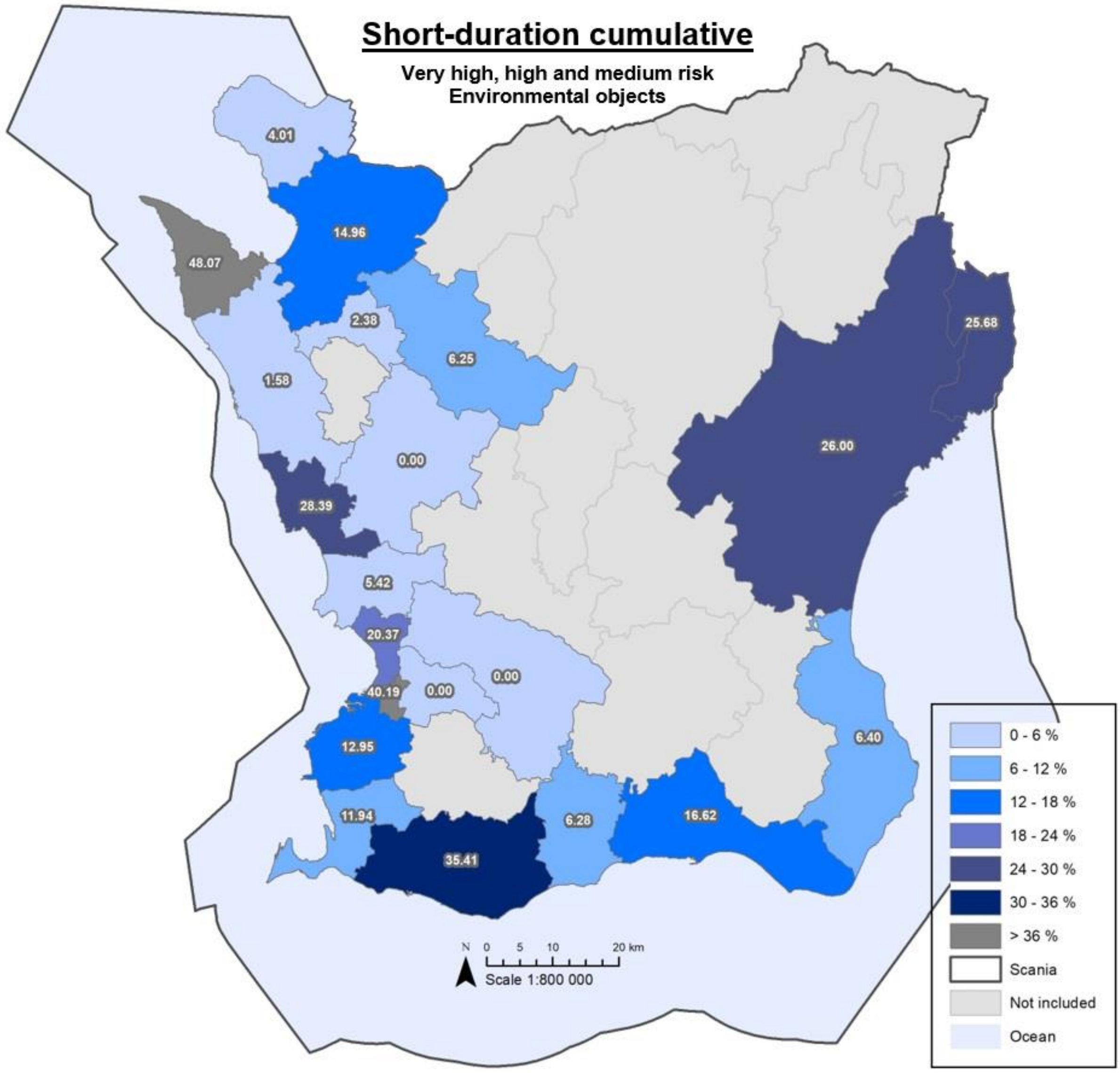

Figure 9. Cumulative map showing the average percentage of environmental objects positioned within the short-duration very high, high and medium risk levels, i.e. below 5.0 m a. s. l. Light blue indicates lower percentages while dark blue indicates higher.

In about two thirds of the investigated municipalities, the average percentage of environmental objects affected by both the short-duration, high and medium risk levels is between 0 and 6 %, which figures F2 and F3, appendix F, illustrates. The average is 6 – 12 % within the high risk level for three municipalities and in medium risk level for five, while one municipality has an average of 18 – 24 % for the high risk level and another one has 24 – 30 % for the medium risk level.

The accumulation of average percentage of environmental objects affected by the short-duration very high, high and medium risk levels shown in figure 9 indicates that an increase in sea level of up to 5.0 meters could have large impacts on these features.

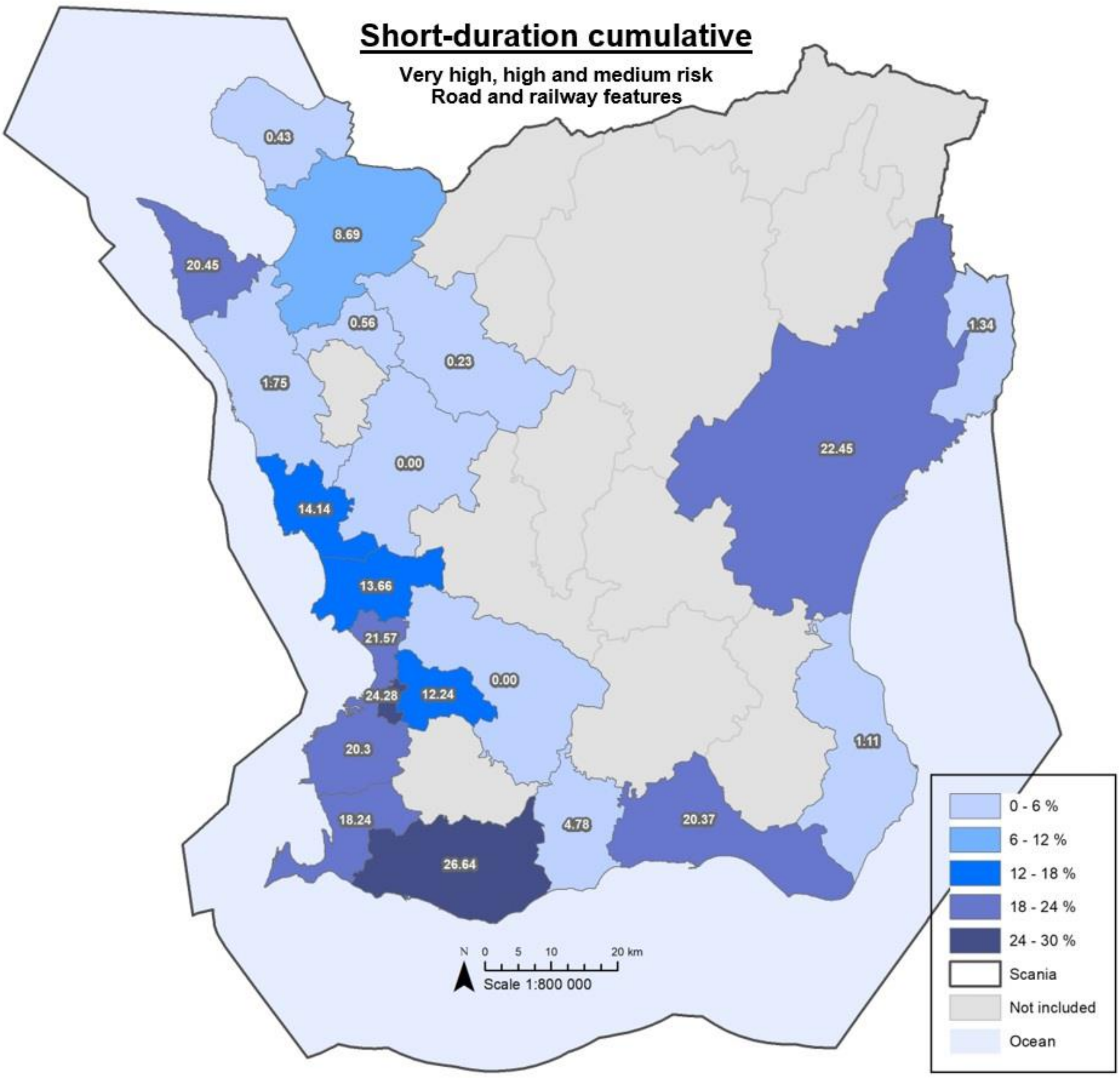

Figure 10. Cumulative map showing the average percentage of road and railway features positioned within the short-duration very high, high and medium risk levels, i.e. below 5.0 m a. s. l. Light blue indicates lower percentages while dark blue indicates higher.

The average percentage of affected road and railway features is 0 to 6 % in about half of the analyzed municipalities for both the short-duration very high and high risk levels, which figures G1 and G2, appendix G, shows. The remaining municipalities have an average of 6 to 12 %, five municipalities have this range within the very high risk level while only three have it for the high risk level.

About half of the analyzed municipalities have an average of 0 to 6 % road and railway features affected by the short-duration, medium risk level, while the average is 6 – 12 % and 12 – 18 % for a quarter of the municipalities each. This is shown in figure G3, appendix G.

An accumulation of the average percentage of road and railway features affected by the short-duration very high, high and medium risk levels indicate that the effects of an increase in sea level of up to 5.0 m differ between different municipalities, as is shown in figure 10. For about half of the municipalities, only a few percent of the road and railway features are affected, but in the other municipalities, the effect is greater. One municipality has an average percentage of 6 – 12 %, while three other has 12 – 18 %. Of the remaining municipalities, six have averages of 18 – 24 %, while one has 24 – 30 %.

4.3 Detailed study of two affected municipalities

Two municipalities were selected for a detailed study of the effects of mean sea level rise and highest projected high water; Kristianstad and Vellinge.

Kristianstad was selected as it is the 4th largest city in Scania and the municipality has the largest area affected by both the short- and long-duration very high risk levels of all municipalities, with 33.21 and 115.67 km^2, respectively. Plus, the highest percentage of a municipality affected by the long-duration, very high risk level is also located in Kristianstad, with 2.47 %. Vellinge was selected as it has the largest share of land affected by the short-duration, very high risk level at 19.98 %, and the lowest shares for both the short- and long-duration low risk levels, at 64.38 and 75.59 %, respectively. As figure 6 shows, it is the municipality that is most affected by both short- and long-duration increases in sea level.

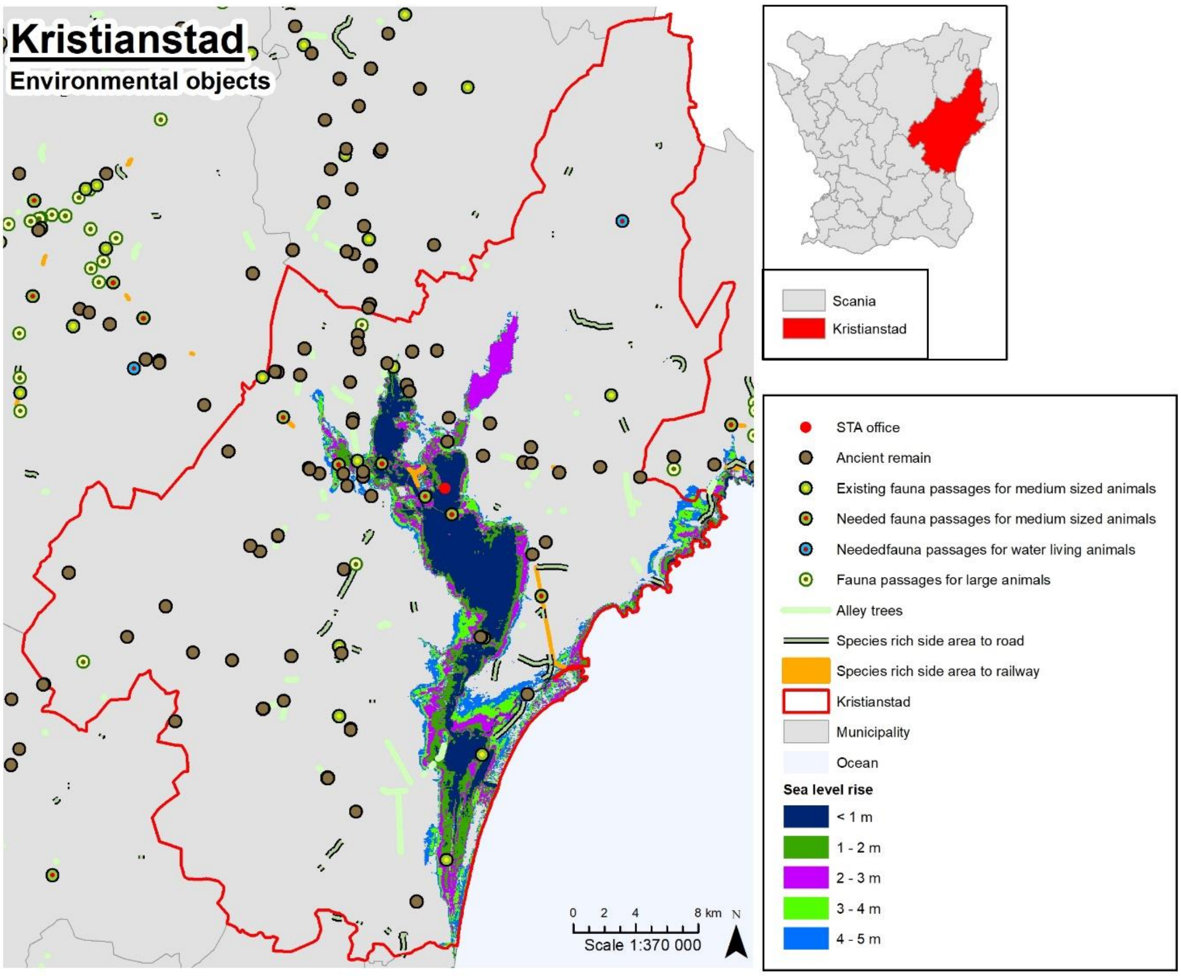

Figure 11. Kristianstad municipality marked by a red border in detail, with red area in the overview of Scania. The environmental objects in the region are shown as well as the analyzed sea levels.

The analyzed increases in sea level in Kristianstad are focused along the coast and the center of the municipality, including the center of Kristianstad city in which the STA's office is located in an area which would be affected by a sea level of under 1 m a. s. l.. Figure 11 shows environmental objects in relation to different sea levels, and some parts of all features except needed fauna passages for water living fauna are located within the analyzed sea levels. However, a large share of each environmental object is located outside of the areas affected by rising seas.

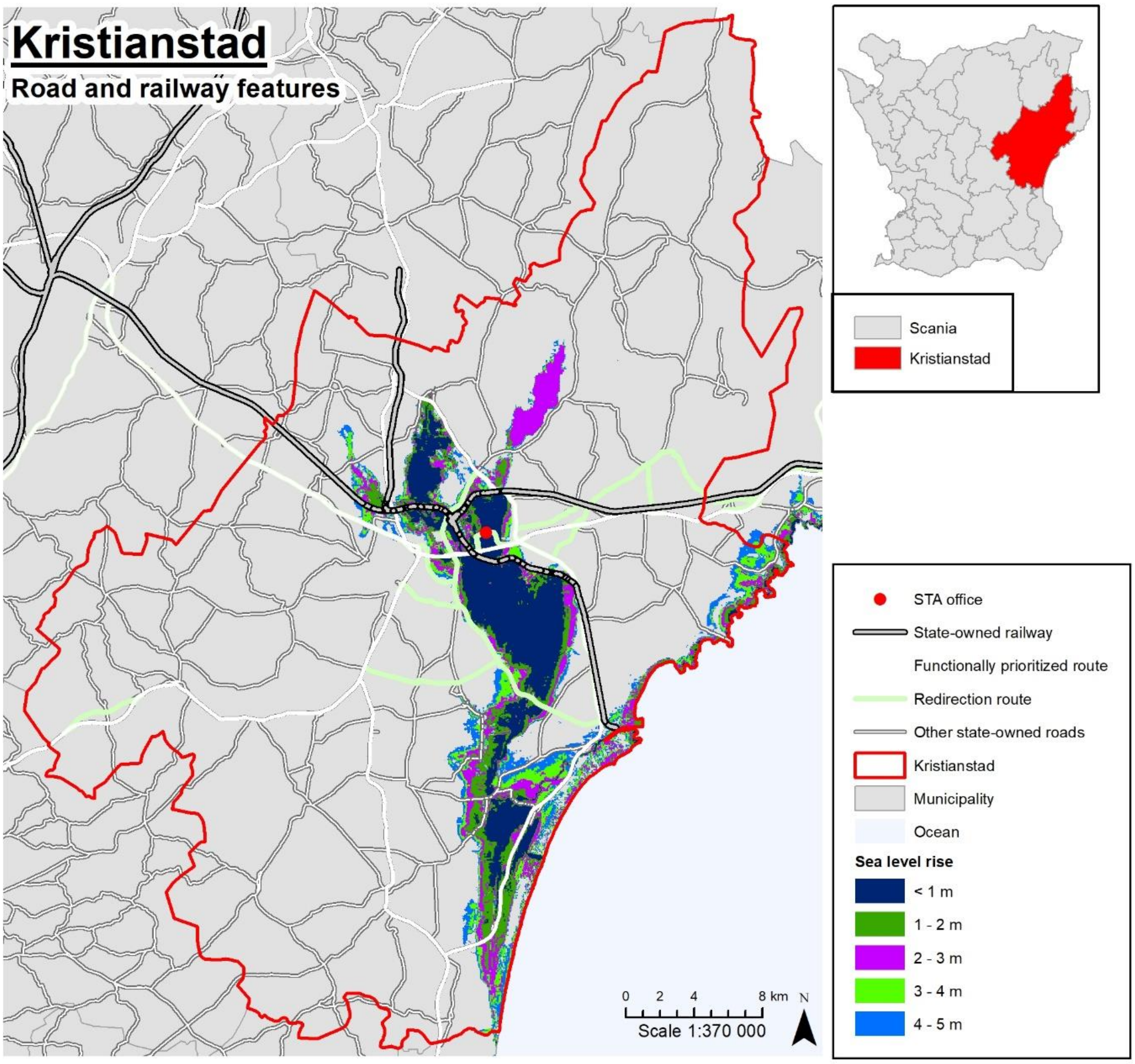

Figure 12. Kristianstad municipality marked by a red border in detail, with red area in the overview of Scania. The road and railway features in the region are shown as well as the analyzed sea levels.

The infrastructure in the municipality is for the most part unaffected by the analyzed sea levels, but all four road and railway features are greatly affected in the central part of the municipality, where the area most vulnerable to an increasing sea level is located, as is illustrated in figure 12. Along the coast, there is a long stretch of functionally prioritized roads in an area affected by the analyzed sea levels and several state-owned roads and redirection routes have minor parts entering these areas. However, as both roads and railways consist of long, connected parts, even a small part of the center or end of a road or railway affected by increasing sea levels could have great effect on the feature. For example, if the entire dark blue area positioned below 1 m a. s. l. was to be inundated, both roads and railways would have to reroute far north of their current locations.

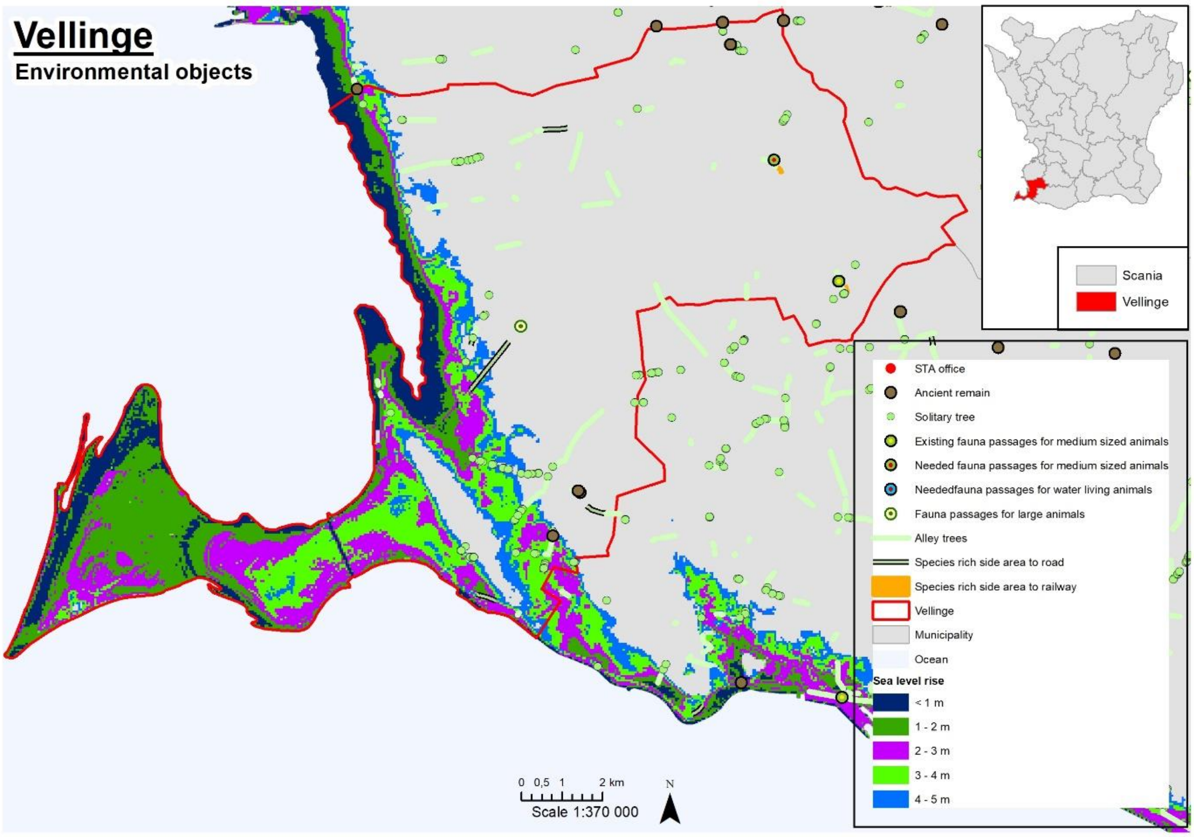

Figure 13. Vellinge municipality marked by a red border in detail, with red area in the overview of Scania. The environmental objects in the region are shown as well as the analyzed sea levels.

The southwestern part of Vellinge municipality is positioned lower than the analyzed sea levels, and hence at risk of inundation. However, only minor shares of alley trees, ancient remains and solitary trees as well as species rich side areas to roads exist in this area, as is shown in figure 13. Road features are on the other hand more affected by the analyzed increases in sea level, as figure 14 shows that a long stretch of both functionally prioritized roads and redirection routes and a smaller part of other state-owned roads are located in areas at risk of inundation. However, as state-owned railways are only found in the northeastern part of the municipality, they are not affected by the analyzed sea levels.

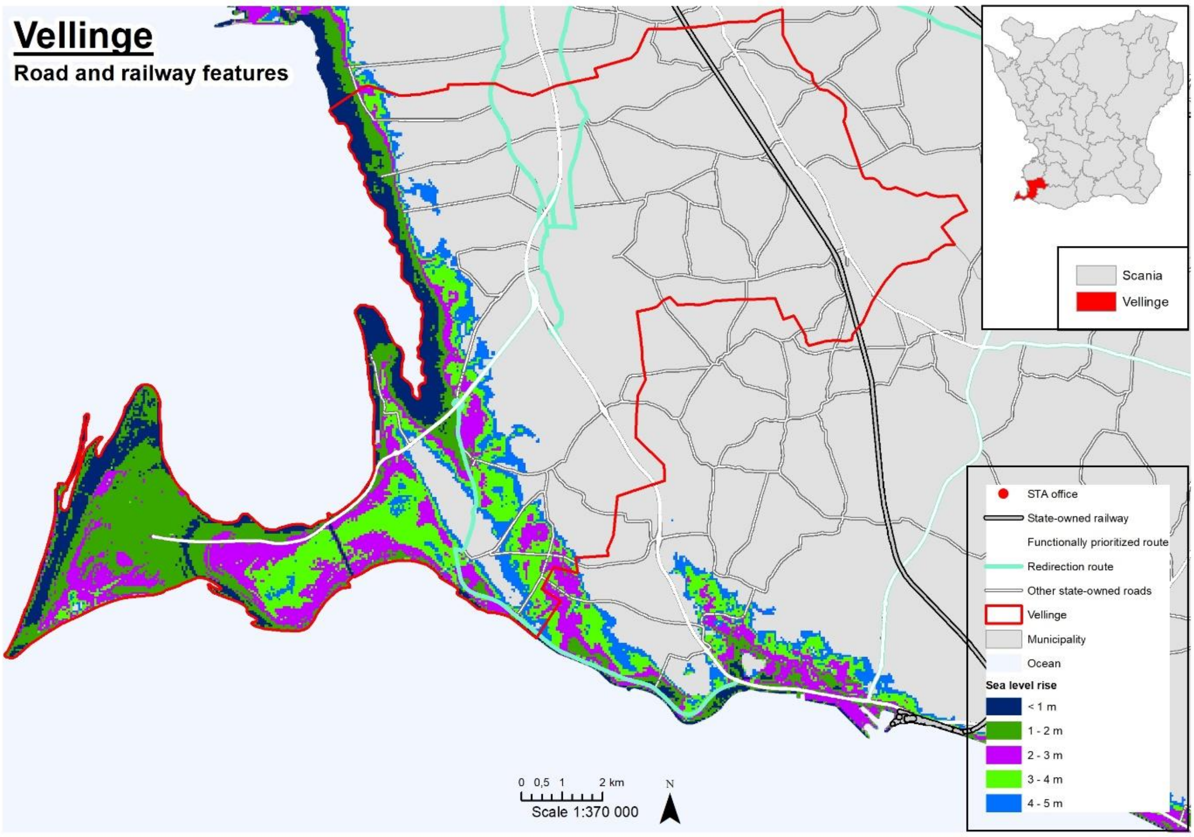

Figure 14. Vellinge municipality marked by a red border in detail, with red area in the overview of Scania. The road and railway features in the region are shown as well as the analyzed sea levels.

4.4 Probability of different sea level rises

As the eight analyzed risk levels are based on two different factors, sea level rise with or without highest projected high water, and highest projected high water in this aspect is viewed as a constant level of 2.0 meters. The probability of each very high, high, medium or low risk level on both short- or long-duration are based on the sea levels' probabilities. In table 8, the likely timeframes for each of the four sets of risk levels is summarized, together with both the short- and the long-duration rise linked to each of the risk levels. These probabilities are based on table 1.

Table 8. Probable timeframes for the very high, high, medium and low risk levels on both short- and long-duration basis as well as the source for the predictions of likelihood.

Risk level	Long-duration rise	Short-duration rise	Likely year	Source for likelihood
Very high	< 0.5m	< 2.5 m	2050 - 2100	IPCC (2013); Kopp et al. (2014)
High	0.5 - 1.0 m	2.5 - 3.0 m	2100 - 2300	IPCC (2013); Kopp et al. (2014)
Medium	1.0 - 3.0 m	3.0 - 5.0 m	2200 - 2300	IPCC (2013); Kopp et al. (2014)
Low	> 3.0 m	> 5.0 m	Beyond 2300	Above all likely projections

5 Discussion

5.1 Effects of analyzed sea levels with or without highest projected high water

Each of the analyzed risk levels for increasing sea levels affect Scania to some extent as shown in figures 4 and 5, but 95.79 % of the county remains unaffected. The areas at risk of different sea levels are mainly focused to the coasts of Scania, but in some parts of the county, the areas stretch further inland while other parts of the coast are hardly affected even by the largest increases in sea level. According to IPCC (2014b), increased risk of inundation of land areas as well as coastal erosion and flooding are some of the consequences of increasing sea levels, and while this might be the most apparent, an increasing sea level and adherent changes in the hydrological cycle could have larger impacts. This could increase the risk of species extinction as well as force a shift in migration, activities and distribution of both terrestrial and marine species, which in turn could cause a decreasing biodiversity.

Different parts of the landscape will see different effects from an increasing sea level. For some parts, sea level rise could have no effect or even create positive effects like increased production of hydropower, while other parts could be negatively affected by higher water levels, e.g. loss of cultural landscapes (Kovats et al. 2014). For the 15 features included in this study, the effects of higher sea levels differed both between and within road and railway features as well as environmental objects.

Species rich side areas to railways and roads as well as existing and needed fauna passages for medium sized fauna had a higher percentage within both the short- and long-duration risk levels compared to other objects. Existing fauna passages for both water living fauna as well as amphibians and reptiles were on the other hand located completely outside of the analyzed sea levels and of low inundation risk, while the remaining environmental objects had different, smaller percentages affected by the analyzed risk levels.

Of the road and railway features, state-owned railways saw the biggest effects of the analyzed sea levels on both short- and long-duration, however functionally prioritized roads, redirection routes and state-owned roads were also affected to some extent. These results concur with Trafikverket (2018b) which states that both planned and existing parts of the state-owned roads and railways are in risk of being affected by future sea levels, through e.g. inundation. Contamination of both land and water as well as a decrease in transportation and productivity could be the result if roads and railways were to be inundated (Ebert, Ekstedt & Jarsjö 2016).

The short-duration risk levels are based on a mean sea level rise in combination with a highest projected high water of 2.0 meters, while the long-duration risk levels are based solely on mean sea level rise, i.e. each short-duration risk level is based on a higher water level of 2.0 meters than its long-duration equivalent. Hence, it is not surprising to see that the areas and features analyzed are at a larger risk of short-duration inundation than of long-duration inundation. Trafikverket (2018b) states that the state-owned roads and railways have already been affected by both short- and long-duration climate change as roads have been flooded and trains delayed.

5.2 Risks on a municipal level

The risk that the analyzed sea levels on both short- and long-duration poses is different for the municipalities of Scania. 12 of the county's municipalities are positioned at high enough elevation not to be affected by any of the risk levels within this study, while the remaining 21 municipalities are to different extents affected by the analyzed sea levels.

Increasing sea levels have the potential to turn previously attached land into islands (Andréasson 2006), a risk that exists for the two municipalities in the detailed study; Vellinge and Kristianstad. Both have at least one area at higher elevation surrounded by lower land at risk of inundation, which indicates that a rising sea level could turn such higher areas into islands. However, previously attached land areas turning into islands is not the only risk caused by increasing sea levels in the two detailed studied municipalities. In Kristianstad and Vellinge, road and railway features are at risk of inundation and since these features are connected to bigger networks, the inundation of one part of a feature could have effects on large parts of the state-owned road and rail network. Plus, as redirection routes are to replace functionally prioritized roads if anything happens to them, the effects are potentially great if both a functionally prioritized road and adherent redirection route were to be inundated, which is a risk in Kristianstad municipality.

Environmental objects might be affected to different extents in the investigated municipalities, but as they consist of mainly single, non-connected features, the inundation of one, or one part of an, object would likely not affect other environmental objects in the municipality.

5.3 Probability of different sea level rises

The risk levels used for this study are based on likely increases in sea level primarily from Kopp et al. (2014) and IPCC (2013), with the addition of a 2.0 meters highest projected high water for short-duration levels. However, as sea level rise will not be uniform on a global scale (IPCC 2014b), the probable timeframes set in this study might be slightly off since Scania could see a sea level that is either higher or lower than the global mean sea level rise.

Sea level rises from other sources like Sweet et al. (2017) and Parris et al. (2012) were considered to be included in setting the risk levels, but as IPCC (2013) is used by the STA (Trafikverket 2018b) for projections of climate change and sea level rise, Parris et al. (2012) was not included when calculating risk levels, as this publication is older than IPCC (2013). Sweet et al. (2017) presents a more recent study than IPCC (2013) but was not included in the risk levels since Sweet et al. (2017) presents sea level rises of low or unknown confidence. However, both Sweet et al. (2017) and Parris et al. (2012) were included when the probable timeframes for each risk level was set, as IPCC (2013) states that in 2013 the only evidence of larger increases in sea level was insufficient, but also recognizes that there are other studies that support up to twice as big projections as included in AR5.

This study presents increases in sea level that based on current science could occur between 2050 and 2300, but few studies have been made resulting in projection of likely or high confidence sea level rises past 2100. As current GHG emissions are in line with RCP 8.5 (Hayhoe et al. 2018) and IPCC (2014b) indicate that the global sea level is projected to increase beyond 2100, other less confident or less likely projections could be worth considering, like Sweet et al. (2017) or Parris et al. (2012).

Swedish municipalities might need planning for higher sea levels, since they according to Ebert, Ekstedt & Jarsjö (2016) use RCP 8.5 by 2100 in their plans. Länsstyrelsen Skåne (2012), and their recommendation of a minimum elevation of 3.0 meters for new residential buildings and 2.5 meters for commercial buildings, could be viewed as an implication to this, as these levels are well beyond the likely levels by 2100 and are not likely to occur until 2200 (Kopp et al. 2014) or 2300 (IPCC 2013).

5.4 Critical analysis and sources of error

Scania experiences a land uplift of 0.5 – 1.5 mm/year due to the weight the inland ice of the last ice age exerted on land 10 000 years ago (Lantmäteriet 2018). However, land uplift was not included in the analysis for two separate reasons. The first being that to include this, a timeframe for the study would have to be set, whereas the thesis aims at presenting results that could be used for different times. The second reason is that the land uplift in Scania is relatively small, and in 80 years, by 2100, it would be approximately 6 cm (4.0 to 8.0 cm) in the county.

As this study focuses on events on a county or municipality level, the elevation data used has a cell size of 50 meters, but there is also elevation data built with higher resolution, e.g. two meters. With higher resolution, elevation data becomes finer and small changes in elevation are distinguishable in the data, but the data also becomes substantially heavier compared to e.g. a 50-meter cell size. As the file size is limited both for downloads and by computer power, the heavier, high-resolution elevation data might have to be downloaded and analyzed in several separate files while the lighter, low-resolution elevation data can be handled all in one file. An example of this is that to download 50-meter elevation data one file is sufficient for all of Scania, while it would take approximately nine 2-meter elevation files to cover the same area. Plus, while the 50-meter elevation raster is open data, the 2-meter data is not.

The selection of the courser 50-meter elevation data might have resulted in some areas and some features getting a higher or lower elevation than their real elevation, however, a 50-meter cell size is still more suitable for analysis of this spatial extent; an entire county and its municipalities. However, if a similar study was to be performed on a smaller area, e.g. on one or a few municipalities, the high-resolution elevation data would be more suitable than the low-resolution data this thesis uses to study an entire county.

The probabilities, timeframes and ranges of sea level rise could be a source of error, as several sources (e.g. Parris et al. 2012; IPCC 2013; Kopp et al. 2014; Sweet et al. 2017) state different sea levels, on different time frames and based on different evidence. This study does not in any way try to calculate future sea level rise and adherent timeframes, it merely evaluates and weights the available scientific results on the matter to find likely risk levels and scenarios. However, as sea level rise is not uniform across the globe, different regions might see different increases in sea level (IPCC 2014b). This in combination with uncertainty about several drivers of sea level rise, e.g. Antarctic ice sheet loss (IPCC 2013; Sweet et al. 2017), indicates that there is a chance that not even the sea level analyzed as a very high risk, up to 0.5 meters, occurs in Scania for a long time, but there is also a risk that future sea levels quickly exceed the analyzed levels.

5.5 Future research

This thesis covers a limited, but vulnerable, part of Sweden and similar research of the other counties of Sweden could show interesting results and be a good tool for prioritizing preventive action to limit the effects of future sea level rise.

Another aspect that could give useful results is if the short- and long-duration sea level rise would be combined with projected changes in the inland hydrology. This since a rising sea level might slow down the inland flow rates and increase the water levels further inland, which could both cause inundation of its own or amplify the effect that sea level rise could have on land.

A final, and perhaps most vital, idea for future research is to continuously monitor the development of the climate change science and the studies performed within the field. There are today uncertainties about some of the sea level rise drivers like, e.g. Antarctic ice sheet loss, which could with further research prove to have a different effect on sea level rise than the effect that the current projections include.

6 Conclusions

Five percent of Scania's area and 21 of the county's 33 municipalities are at risk of inundation on either short- or long-duration. The areas at risk are mainly positioned along the coasts with some areas stretching further inland.

Species rich side areas to railways and state-owned railways are the two most affected of the investigated features, which implies that the railways and their side areas could be in the biggest need of preventive action to protect them from future increases in sea level. However, species rich side areas to roads as well as existing and needed fauna passages for medium sized fauna are also at a higher risk of both short- and long-duration inundation than the other environmental objects. The environmental objects are when viewed as a group more affected by the risk levels than the road and railway features, but there are environmental objects that are less affected than the road and railway features.

On a municipal level, the effects that both short- and long-duration increases in sea level has on road and railway features as well as environmental objects differs. In some municipalities, only a few percent of the investigated features are affected by each of the very high, high and medium risk levels, while other municipalities are at a larger risk, as they have up to a quarter or a third of their environmental objects and road and rail features affected by at least one of the risk levels. If preventive actions where to be limited, perhaps some of the municipalities with larger shares of features in higher risk levels would be worth considering to include.

The effects of the analyzed sea levels differ between the two detailed studied municipalities, Kristianstad and Vellinge. In Vellinge, some, but not all, features are at large risk of inundation, as large parts of the southwestern half of the municipality are positioned within the very high, high and medium risk levels. Kristianstad, on the other hand, has a large, central area at risk, as the analyzed sea levels stretch from the coast into the land in an area of low elevation. Hence this entire area should be of focus if preventive actions where to be planned to protect state-owned roads and railways as well as environmental objects in the municipality.

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Appendix A. Definitions for the short- and long-duration risk levels.

Longer duration inundation – new global mean sea level:

a. Very high risk of long duration increases in sea level. Areas and features positioned less than 0.5 m a. s. l., as sources states that this is a likely sea level rise by 2050 or 2100 under RCP 8.5 (IPCC 2013; Kopp et al. 2014).
b. High risk of long duration increases in sea level. Areas and features positioned between 0.5 and 1 m a. s. l., as sources states that this is a likely sea level rise by 2100 under RCP 8.5 (IPCC 2013).
c. Medium risk of long duration increases in sea level. Areas and features positioned between 1 and 3 m a. s. l., as sources states that this is a likely sea level rise by 2150, 2200 (Kopp et al. 2014) or 2300 under RCP 8.5 (IPCC 2013).
d. Low risk for of long duration increases in sea level. Areas and features positioned over 3 m a. s. l., as no source states that an increase above 3 m is a likely to occur before 2300 based on current studies.

Shorter duration inundation – storm event; new global mean sea level and highest projected high water:

a. Very high risk of short duration increases in sea level. Areas and features positioned less than 2.5 m a. s. l., as sources states that 0.5 m is a likely sea level rise by 2050 or 2100 under RCP 8.5 (IPCC 2013; Kopp et al. 2014) and the average highest projected high water in Scania is 1.9 m (SMHI 2018b).
b. High risk of short duration increases in sea level. Areas and features positioned between 2.5 and 3 m a. s. l., as sources states that 0.5 to 1.0 m is a likely sea level rise by 2100 under RCP 8.5 (IPCC 2013) and the average highest projected high water in Scania is 1.9 m (SMHI 2018b).
c. Medium risk of short duration increases in sea level. Areas and features positioned between 3 and 5 m a. s. l., as sources states that this is a likely sea level rise by 2150, 2200 (Kopp et al. 2014) or 2300 under RCP 8.5 (IPCC 2013) and the average highest projected high water in Scania is 1.9 m (SMHI 2018b).
d. Low risk of short duration increases in sea level. Areas and features positioned over 5 m a. s. l., as no source states that an increase above 3 m is a likely to occur before 2300 based on current studies and the average highest projected high water in Scania is 1.9 m (SMHI 2018b).

Appendix B. Municipal effects of risk levels.

Percentage of each municipality affected by the eight risk levels, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality.

Risk	Long-duration					Short-duration				
	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	0.24	0.29	0.96	98.39	1.61	1.22	0.27	1.83	96.57	3.43
Burlöv	0.25	0.45	8.33	90.88	9.12	5.26	3.77	13.53	77.34	22.66
Båstad	0.23	0.13	0.91	98.57	1.43	0.93	0.35	1.40	97.17	2.83
Helsingborg	0.11	0.06	1.06	98.71	1.29	0.88	0.35	0.95	97.77	2.23
Höganäs	0.62	1.16	8.51	89.48	10.52	7.84	2.45	10.80	78.68	21.32
Klippan	-	-	0.47	99.53	0.47	0.36	0.11	0.35	99.18	0.82
Kristianstad	2.47	2.14	5.20	90.16	9.84	8.60	1.21	4.12	86.05	13.95
Kävlinge	0.70	0.63	4.98	93.62	6.38	5.12	1.19	5.83	87.80	12.20
Landskrona	0.66	0.90	5.89	92.44	7.56	6.28	1.17	4.07	88.37	11.63
Lomma	2.23	2.39	14.66	80.58	19.42	15.03	4.23	11.39	69.21	30.79
Lund	-	-	-	100.00	-	-	-	0.02	99.98	-
Malmö	1.76	1.34	11.70	84.99	15.01	9.63	5.17	7.05	77.95	22.05
Simrishamn	0.15	0.09	0.65	99.04	0.96	0.65	0.23	1.03	98.01	1.99
Skurup	0.08	0.13	0.77	98.98	1.02	0.76	0.22	0.95	98.03	1.97
Staffanstorp	-	-	0.20	99.79	0.21	0.10	0.11	0.59	99.20	0.80
Svalöv	-	-	0.02	99.98	0.02	0.01	0.02	0.03	99.95	0.05
Trelleborg	0.15	0.18	3.03	96.58	3.42	2.35	1.00	3.89	92.70	7.30
Vellinge	2.09	4.36	17.72	75.59	24.41	19.98	4.19	11.21	64.38	35.62
Ystad	0.11	0.06	3.39	96.36	3.64	2.13	1.44	5.04	91.32	8.68
Åstorp	0.03	0.01	1.18	98.79	1.21	0.77	0.45	1.95	96.84	3.16
Ängelholm	0.11	0.13	1.87	97.85	2.15	1.54	0.58	2.57	95.28	4.72

Appendix C. Risk levels' effect on analyzed features.

Table C1. Percentage of the total length of alley trees affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Alley trees

	Long-duration					**Short-duration**				
Risk	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	-	-	-	100.00	-	-	-	30.95	69.05	30.95
Burlöv										
Båstad	-	-	-	100.00	-	-	-	0.01	99.99	0.01
Helsingborg	-	-	-	100.00	-	-	-	1.96	98.04	1.96
Höganäs	-	0.07	11.42	88.51	11.49	6.02	5.47	28.83	59.68	40.32
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	-	-	3.45	96.55	3.45	1.90	1.55	1.57	94.97	5.03
Kävlinge	-	-	0.95	99.05	0.95	0.10	0.85	12.95	86.09	13.91
Landskrona	-	-	-	100.00	-	-	-	-	100.00	-
Lomma	-	-	12.82	87.18	12.82	7.71	5.11	5.98	81.20	18.80
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	9.31	90.69	9.31	9.31	-	6.02	84.67	15.33
Simrishamn	-	-	-	100.00	-	-	-	-	100.00	-
Skurup	-	-	7.18	92.82	7.18	6.26	0.92	10.93	81.90	18.10
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	0.06	6.86	93.08	6.92	4.96	1.97	5.86	87.21	12.79
Vellinge	-	-	1.32	98.68	1.32	1.19	0.13	6.68	92.00	8.00
Ystad	-	0.06	0.07	99.88	0.12	0.06	0.07	5.17	94.71	5.29
Åstorp										
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C2. Percentage of the total number of ancient remains affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality.

Ancient remains

	Long-duration					**Short-duration**				
Risk	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	-	-	-	100.00	-	-	-	33.33	66.67	33.33
Burlöv	-	-	-	100.00	-	-	-	-	100.00	-
Båstad	-	-	-	100.00	-	-	-	-	100.00	-
Helsingborg	-	-	-	100.00	-	-	-	-	100.00	-
Höganäs	-	-	-	100.00	-	-	-	-	100.00	-
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	-	1.47	-	98.53	1.47	1.47	-	2.94	95.59	4.41
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	-	-	-	100.00	-	-	-	-	100.00	-
Lomma	-	-	-	100.00	-	-	-	-	100.00	-
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	16.67	83.33	16.67	16.67	-	0.00	83.33	16.67
Simrishamn	-	-	-	100.00	-	-	-	-	100.00	-
Skurup	-	-	-	100.00	-	-	-	7.14	92.86	7.14
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	-	16.67	83.33	16.67	11.11	5.56	-	83.33	16.67
Vellinge	-	-	-	100.00	-	-	-	25.00	75.00	25.00
Ystad	-	-	-	100.00	-	-	-	9.10	90.90	9.10
Åstorp	-	-	-	100.00	-	-	-	-	100.00	-
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C3. Percentage of the total length of existing fauna passages for amphibians and reptiles affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Existing fauna passages for amphibians and reptiles

	Long-duration					**Short-duration**				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla										
Burlöv										
Båstad										
Helsingborg										
Höganäs										
Klippan										
Kristianstad										
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	-	-	-	100.00	-	-	-	-	100.00	-
Lomma										
Lund										
Malmö										
Simrishamn										
Skurup										
Staffanstorp										
Svalöv										
Trelleborg										
Vellinge										
Ystad	-	-	-	100.00	-	-	-	-	100.00	-
Åstorp										
Ängelholm										

Table C4. Percentage of the total number of fauna passages for large fauna affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Fauna passages for large fauna

	Long-duration					Short-duration				
Risk	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	-	-	-	100.00	-	-	-	-	100.00	-
Burlöv	-	-	25.00	75.00	25.00	-	25.00	25.00	50.00	50.00
Båstad	-	-	-	100.00	-	-	-	-	100.00	-
Helsingborg	-	-	-	100.00	-	-	-	-	100.00	-
Höganäs	-	-	-	100.00	-	-	-	-	100.00	-
Klippan	-	-	12.50	87.50	12.50	-	12.50	12.50	75.00	25.00
Kristianstad	-	-	-	100.00	-	-	-	-	100.00	-
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	-	-	33.33	66.67	33.33	33.33	-	-	66.76	33.24
Lomma	-	-	-	100.00	-	-	-	-	100.00	-
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	-	100.00	-	-	-	-	100.00	-
Simrishamn										100.00
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleberg										100.00
Vellinge	-	-	-	100.00	-	-	-	-	100.00	-
Ystad	-	-	-	100.00	-	-	-	-	100.00	-
Åstorp	-	-	14.29	85.71	14.29	-	14.29	-	85.71	14.29
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C5. Percentage of the total number of existing fauna passages for medium sized fauna affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Existing fauna passages for medium sized fauna

	Long-duration					Short-duration				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	-	100.00	0.00	-	-	-	100.00	-
Burlöv										
Båstad										
Helsingborg	-	-	-	100.00	0.00	-	-	-	100.00	-
Höganäs	33.33	-	66.67	-	100.00	66.67	33.33	-	-	100.00
Klippan	-	-	-	100.00	0.00	-	-	-	100.00	-
Kristianstad	11.11	22.22	22.22	44.44	55.56	55.56	-	11.11	33.33	66.67
Kävlinge										
Landskrona										
Lomma										
Lund										
Malmö										
Simrishamn										
Skurup										
Staffanstorp										
Svalöv	-	-	-	100.00	0.00	-	-	-	100.00	-
Trelleborg	-	-	100.00	-	100.00	-	100.00	-	-	100.00
Vellinge	-	-	-	100.00	0.00	-	-	-	100.00	-
Ystad										
Åstorp	-	-	-	100.00	0.00	-	-	-	100.00	-
Ängelholm	-	-	-	100.00	0.00	-	-	-	100.00	-

Table C6. Percentage of the total number of needed fauna passages for medium sized fauna affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Needed fauna passages for medium sized fauna

	Long-duration					**Short-duration**				
Risk	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	-	-	-	100.00	-	-	-	50.00	50.00	50.00
Burlöv	-	-	100.00	0.00	100.00	100.00	-	-	0.00	100.00
Båstad										
Helsingborg	-	-	-	100.00	-	-	-	9.09	90.91	9.09
Höganäs	-	-	100.00	0.00	100.00	100.00	-	-	0.00	100.00
Klippan	-	-	-	100.00	-	-	-	25.00	75.00	25.00
Kristianstad	-	16.67	33.33	50.00	50.00	33.33	16.67	16.67	33.33	66.67
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	33.33	-	33.33	33.33	66.67	66.67	-	-	33.33	66.67
Lomma	-	-	100.00	0.00	100.00	50.00	50.00	-	0.00	100.00
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	-	100.00	-	-	-	-	100.00	-
Simrishamn	-	-	-	100.00	-	-	-	25.00	75.00	25.00
Skurup	-	-	-	100.00	-	-	-	25.00	75.00	25.00
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	-	-	100.00	-	-	-	-	100.00	-
Vellinge	-	-	-	100.00	-	-	-	-	100.00	-
Ystad	-	-	33.33	66.67	33.33	33.33	-	16.67	50.00	50.00
Åstorp	-	-	-	100.00	-	-	-	-	100.00	-
Ängelholm	20.00	-	20.00	60.00	40.00	40.00	-	20.00	40.00	60.00

Table C7. Percentage of the total number of needed fauna passages for water living fauna affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Needed fauna passages for water living fauna

Risk	Long-duration					Short-duration				
Municipality	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla										
Burlöv										
Båstad	-	-	-	100.00	-	-	-	-	100.00	-
Helsingborg	-	-	-	100.00	-	-	-	-	100.00	-
Höganäs										
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	-	-	-	100.00	-	-	-	-	100.00	-
Kävlinge										
Landskrona										
Lomma										
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	-	100.00	-	-	-	-	100.00	-
Simrishamn	-	-	-	100.00	-	-	-	-	100.00	-
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg										
Vellinge										
Ystad	-	-	-	100.00	-	-	-	33.33	66.67	33.33
Åstorp										
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C8. Percentage of the total number of solitary trees affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Solitary trees

	Long-duration					**Short-duration**				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla										
Burlöv										
Båstad										
Helsingborg										
Höganäs										
Klippan										
Kristianstad										
Kävlinge	-	-	-	100.00	-	-	-	14.63	85.37	14.63
Landskrona	-	-	7.69	92.31	7.69	7.69	-	7.69	84.62	15.38
Lomma	-	-	-	100.00	-	-	-	-	100.00	-
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	-	-	100.00	-	-	-	-	100.00	-
Simrishamn										
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	-	-	100.00	-	-	-	4.95	95.05	4.95
Vellinge	-	-	3.88	96.12	3.88	1.94	2.91	31.07	64.08	35.92
Ystad	-	-	-	100.00	-	-	-	-	100.00	-
Åstorp										
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C9. Percentage of the total area of species rich side areas to railways affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Species rich side areas to railways

Risk	Long-duration					Short-duration				
Municipality	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	0.97	99.03	0.97	-	0.97	62.50	66.53	33.47
Burlöv	3.26	-	0.11	96.63	3.37	-	0.11	10.62	89.27	10.73
Båstad	-	-	-	100.00	-	-	-	0.04	99.96	0.04
Helsingborg	-	-	-	100.00	-	-	-	-	100.00	-
Höganäs										
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	0.76	-	25.50	73.73	26.27	9.30	16.97	26.15	47.58	52.42
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	-	-	54.79	45.21	54.79	54.36	0.43	0.15	45.06	54.94
Lomma	-	-	-	100.00	-	-	-	3.35	96.65	3.35
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	0.01	0.03	46.32	53.64	46.36	15.92	30.70	11.96	41.42	58.58
Simrishamn	-	-	-	100.00	-	-	-	-	100.00	-
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	0.03	0.95	84.56	14.46	85.54	34.87	50.67	9.61	4.85	95.15
Vellinge	-	-	-	100.00	-	-	-	-	100.00	-
Ystad	-	-	46.81	53.19	46.81	23.00	23.80	4.93	48.26	51.74
Åstorp	-	-	-	100.00	-	-	-	-	100.00	-
Ängelholm	-	-	-	100.00	-	-	-	74.66	25.34	74.66

Table C10. Percentage of the total length of species rich side areas to roads affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

<u>Species rich side areas to roads</u>

	Long-duration					**Short-duration**				
Risk	Very high	High	Medium	Low	Medium, High and Very high	Very high	High	Medium	Low	Medium, High and Very high
Municipality	%	%	%	%	%	%	%	%	%	%
Bromölla	-	-	-	100.00	-	-	-	2.01	97.99	2.01
Burlöv										
Båstad	-	-	3.82	96.18	3.82	3.82	-	20.18	76.00	24.00
Helsingborg										
Höganäs										
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	0.02	-	-	99.98	0.02	0.02	-	12.73	87.24	12.76
Kävlinge	-	-	0.87	99.13	0.87	-	0.87	13.94	85.19	14.81
Landskrona										
Lomma										
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö										
Simrishamn	-	-	8.84	91.16	8.84	5.90	2.94	4.55	86.61	13.39
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp										
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	-	5.53	94.47	5.53	0.93	4.60	12.74	81.73	18.27
Vellinge	-	-	0.74	99.26	0.74	-	0.74	25.91	73.35	26.65
Ystad	-	-	-	100.00	-	-	-	0.08	99.92	0.08
Åstorp										
Ängelholm	-	-	-	100.00	-	-	-	-	100.00	-

Table C11. Percentage of the total length of state-owned railways affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

State-owned railways

	Long-duration					Short-duration				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	0.12	99.88	0.12	-	0.12	1.17	98.71	1.29
Burlöv	1.30	-	11.28	87.42	12.58	3.60	8.98	26.45	60.97	39.03
Båstad	-	-	-	100.00	-	-	-	-	100.00	-
Helsingborg	-	0.24	4.29	95.46	4.54	3.15	1.39	1.67	93.79	6.21
Höganäs										
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	0.59	0.30	26.02	73.10	26.90	12.03	14.88	19.54	53.55	46.45
Kävlinge	-	-	-	100.00	-	-	-	-	100.00	-
Landskrona	-	0.01	19.15	80.84	19.16	18.11	1.05	9.39	71.45	28.55
Lomma	-	0.28	24.71	75.01	24.99	13.73	11.26	12.76	62.25	37.75
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	0.20	0.30	39.86	59.64	40.36	11.80	28.56	12.96	46.68	53.32
Simrishamn	-	-	-	100.00	-	-	-	-	100.00	-
Skurup	-	-	-	100.00	-	-	-	-	100.00	-
Staffanstorp	-	-	0.54	99.46	0.54	0.06	0.26	48.56	51.12	48.88
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	0.06	0.26	48.56	51.12	48.88	17.02	31.87	5.77	45.34	54.66
Vellinge	-	-	-	100.00	-	-	-	-	100.00	-
Ystad	-	-	23.19	76.81	23.19	12.13	11.05	17.08	59.74	40.26
Åstorp	-	-	-	100.00	-	-	-	-	100.00	-
Ängelholm	0.44	-	3.42	96.14	3.86	1.60	2.26	27.99	68.15	31.85

Table C12. Percentage of the total length of redirection routes affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality, while a feature that is not found within a municipality is marked with a blank row.

Redirection routes

	Long-duration					**Short-duration**				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	-	100.00	0.00	-	-	0.96	99.04	0.96
Burlöv	0.62	-	11.99	87.39	12.61	5.59	7.03	10.64	76.75	23.25
Båstad	-	-	-	100.00	-	-	-	-	100.00	-
Helsingborg	-	-	0.09	99.91	0.09	0.05	0.03	0.18	99.74	0.26
Höganäs										
Klippan	-	-	-	100.00	-	-	-	-	100.00	-
Kristianstad	4.03	0.66	7.39	87.93	12.07	9.59	2.48	8.37	79.56	20.44
Kävlinge	0.17	-	3.78	96.05	3.95	2.01	1.94	28.79	67.26	32.74
Landskrona	-	0.25	2.50	97.25	2.75	1.35	1.40	3.22	94.03	5.97
Lomma	0.07	-	2.62	97.31	2.69	2.16	0.53	13.56	83.74	16.26
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	1.14	0.35	7.67	90.84	9.16	5.31	3.85	7.31	83.52	16.48
Simrishamn										
Skurup	-	-	-	100.00	-	-	-	2.17	97.83	2.17
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	0.01	0.13	8.23	91.63	8.37	5.48	2.89	6.82	84.81	15.19
Vellinge	0.72	0.00	12.51	86.76	13.24	9.00	4.23	14.17	72.59	27.41
Ystad	-	0.17	2.60	97.24	2.76	1.16	1.60	20.39	76.85	23.15
Åstorp	-	-	-	100.00	-	-	-	-	100.00	-
Ängelholm	-	-	0.04	99.96	0.04	0.04	-	1.02	98.94	1.06

Table C13. Percentage of the total length of functionally prioritized roads affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality.

Functionally prioritized roads

	Long-duration					**Short-duration**				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	-	100.00	-	-	-	0.23	99.77	0.23
Burlöv	-	-	9.20	90.80	9.20	3.58	5.62	9.65	81.15	18.85
Båstad	-	-	0.13	99.87	0.13	0.13	0.00	0.40	99.47	0.53
Helsingborg	-	-	-	100.00	-	-	-	-	100.00	-
Höganäs	-	0.24	10.40	89.35	10.65	4.49	6.15	14.11	75.24	24.76
Klippan	-	-	0.49	99.51	0.49	0.31	0.18	0.15	99.35	0.65
Kristianstad	1.94	0.36	6.23	91.48	8.52	6.65	1.87	6.43	85.05	14.95
Kävlinge	0.01	0.19	1.12	98.69	1.31	1.02	0.30	11.05	87.63	12.37
Landskrona	0.10	0.12	9.89	89.90	10.10	4.96	5.14	4.23	85.67	14.33
Lomma	0.09	-	1.76	98.15	1.85	0.65	1.20	13.05	85.10	14.90
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	0.22	0.06	5.59	94.13	5.87	2.96	2.91	1.03	93.11	6.89
Simrishamn	-	-	0.03	99.97	0.03	0.03	-	0.73	99.24	0.76
Skurup	-	-	5.00	95.00	5.00	3.47	1.53	8.78	86.22	13.78
Staffanstorp	-	-	-	100.00	-	-	-	-	100.00	-
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	-	13.48	86.52	13.48	9.64	3.84	13.85	72.67	27.33
Vellinge	0.50	0.01	18.37	81.11	18.89	15.91	2.98	6.25	74.86	25.14
Ystad	-	0.06	4.02	95.92	4.08	2.26	1.82	8.13	87.80	12.20
Åstorp	-	-	0.57	99.43	0.57	0.41	0.16	0.33	99.10	0.90
Ängelholm	-	-	0.10	99.90	0.10	0.10	-	0.92	98.98	1.02

Table C14. Percentage of the total length of state-owned roads affected by the eight risk levels, within each municipality, as well as two rows showing accumulated percentage for the very high, high and medium risk levels. The percentage is calculated separately for the short- and long-duration levels, and hence the short- and long-duration risk levels respectively have a total of 100 %. Cells with a dash indicates that no part of the feature is located within the risk level in the municipality.

State-owned roads

	Long-duration					Short-duration				
Risk / **Municipality**	Very high %	High %	Medium %	Low %	Medium, High and Very high %	Very high %	High %	Medium %	Low %	Medium, High and Very high %
Bromölla	-	-	0.56	99.44	0.56	0.23	0.33	2.33	97.11	2.89
Burlöv	-	-	6.90	93.10	6.90	3.12	3.78	9.11	83.99	16.01
Båstad	0.01	-	0.25	99.73	0.27	0.16	0.11	0.91	98.82	1.18
Helsingborg	0.02	-	0.04	99.94	0.06	0.04	0.02	0.47	99.47	0.53
Höganäs	-	0.13	6.24	93.63	6.37	3.22	3.15	9.76	83.86	16.14
Klippan	-	-	0.16	99.84	0.16	0.10	0.06	0.13	99.72	0.28
Kristianstad	0.90	0.15	3.13	95.82	4.18	3.11	1.07	3.75	92.07	7.93
Kävlinge	0.03	0.06	1.14	98.78	1.22	0.76	0.46	8.27	90.50	9.50
Landskrona	0.03	0.04	4.17	95.76	4.24	2.15	2.10	3.48	92.28	7.72
Lomma	0.07	0.23	4.09	95.61	4.39	2.93	1.46	12.99	82.62	17.38
Lund	-	-	-	100.00	-	-	-	-	100.00	-
Malmö	-	0.07	3.58	96.35	3.65	1.88	1.76	0.84	95.51	4.49
Simrishamn	-	0.03	0.74	99.23	0.77	0.37	0.40	1.82	97.41	2.59
Skurup	-	-	1.14	98.86	1.14	0.79	0.34	1.99	96.87	3.13
Staffanstorp	-	-	-	100.00	-	-	-	0.04	99.96	0.04
Svalöv	-	-	-	100.00	-	-	-	-	100.00	-
Trelleborg	-	0.05	4.19	94.76	5.24	2.80	1.44	5.12	90.64	9.36
Vellinge	0.32	0.17	10.45	89.05	10.95	8.54	2.41	9.45	79.60	20.40
Ystad	0.01	0.01	1.62	98.36	1.64	0.83	0.81	4.19	94.17	5.83
Åstorp	-	-	0.46	99.54	0.46	0.28	0.18	0.86	98.68	1.32
Ängelholm	-	-	0.14	99.86	0.14	0.07	0.07	0.69	99.17	0.83

Appendix D. Long-duration risk level maps for environmental object.

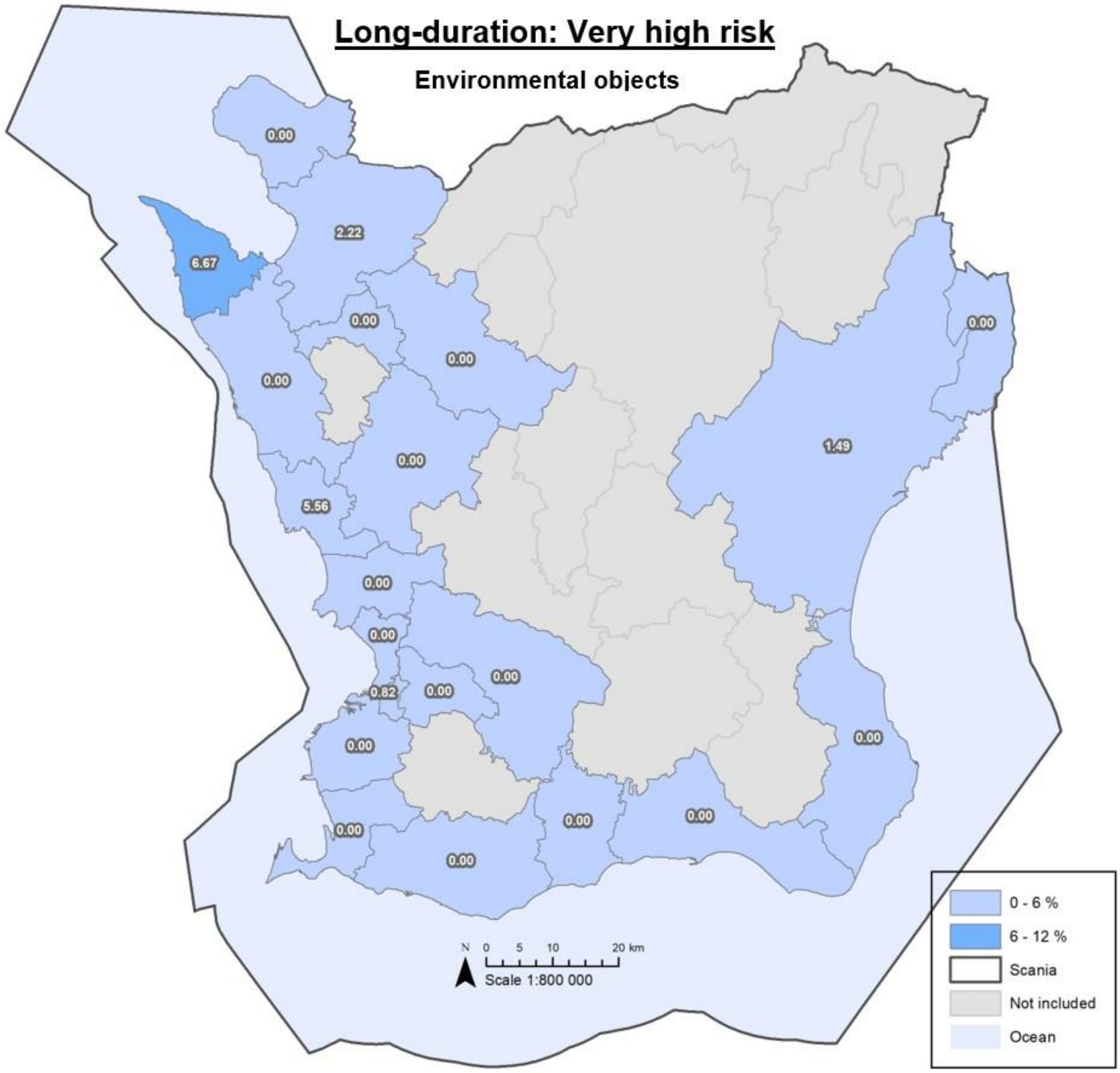

Figure D1. The average percentage of environmental objects positioned below 0.5 m a. s. l. and within the long-duration, very high risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

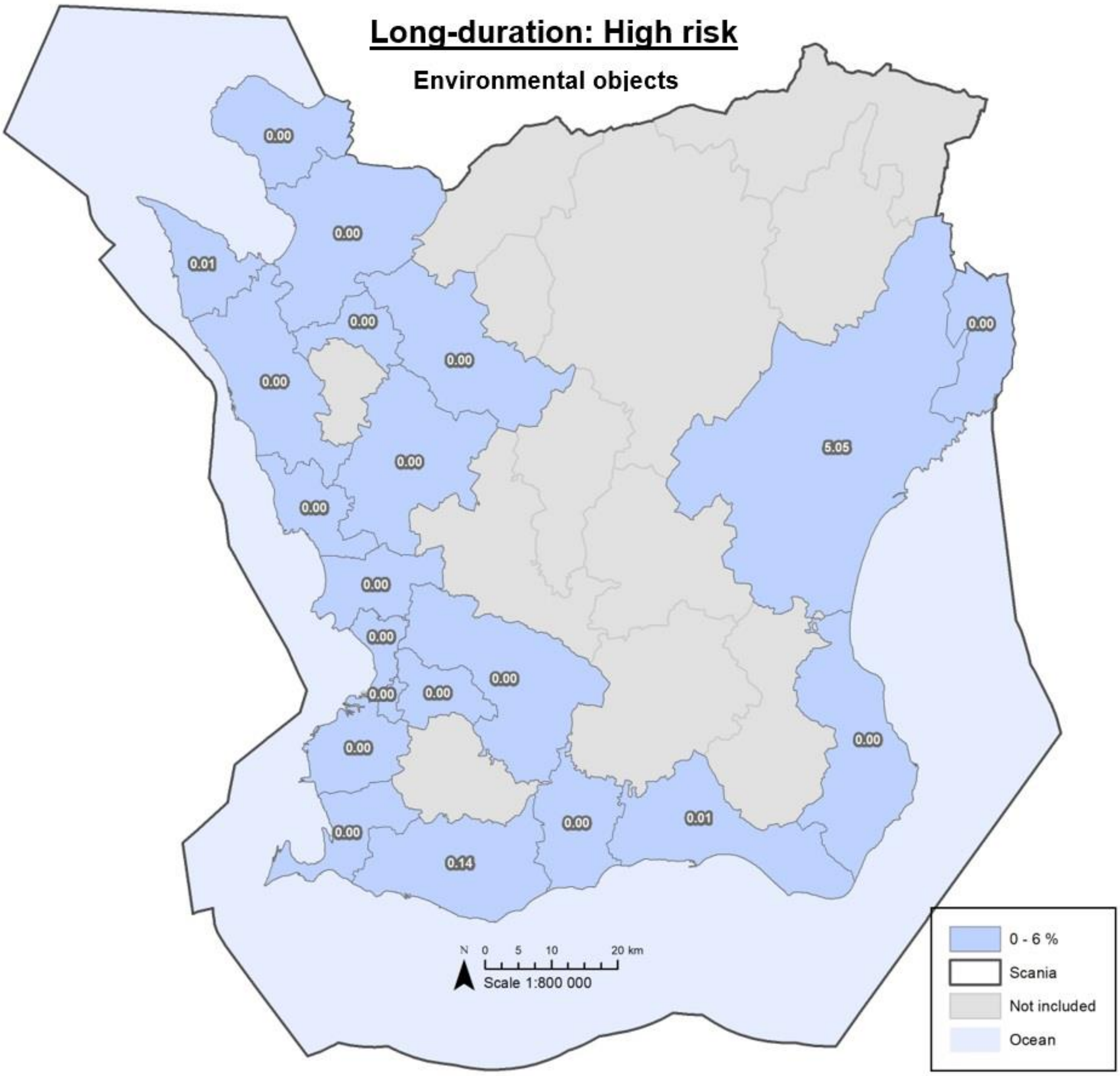

Figure D2. The average percentage of environmental objects positioned between 0.5 and 1.0 m a. s. l. and within the long-duration, high risk level in each municipality.

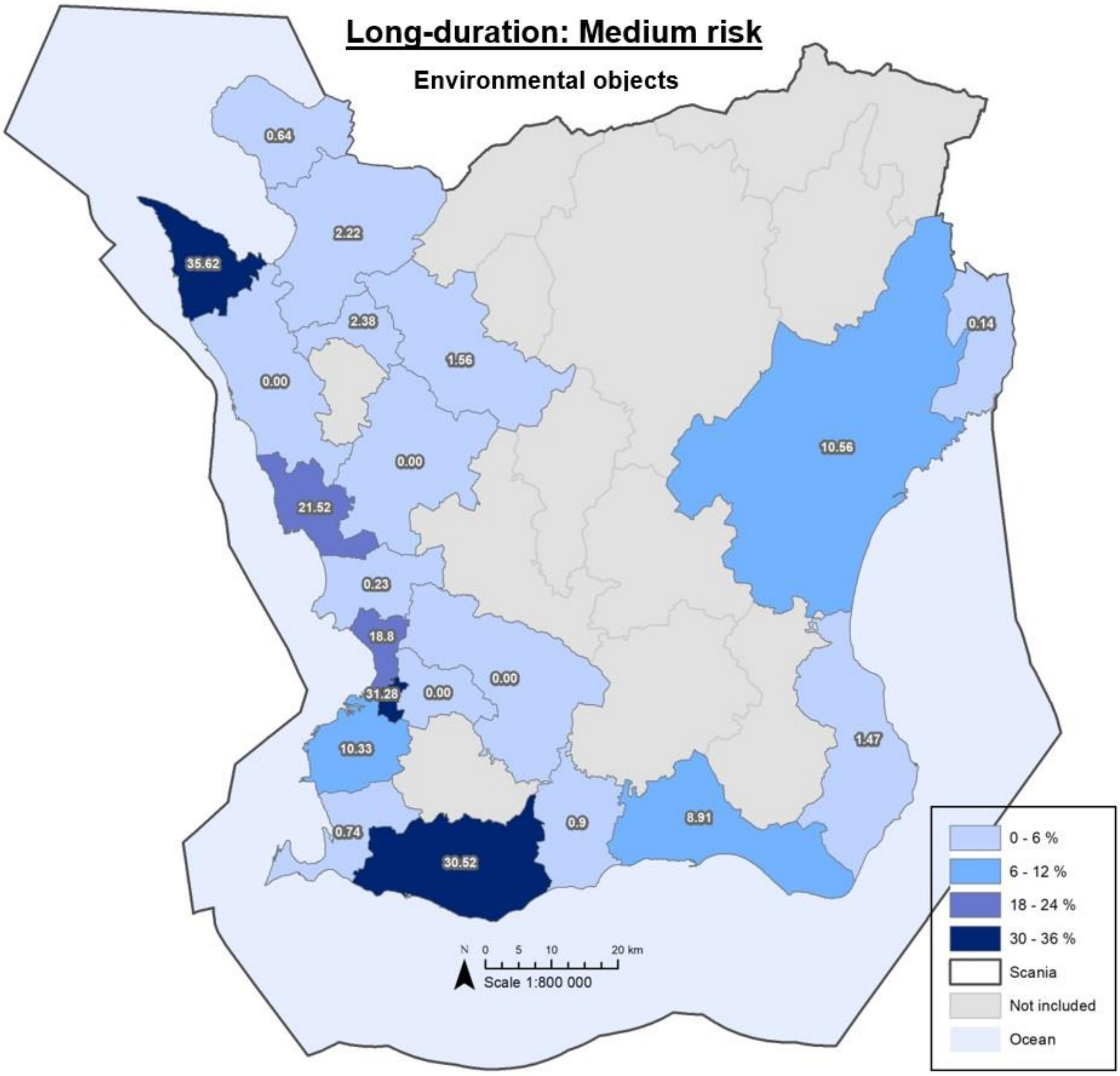

Figure D3. The average percentage of environmental objects positioned between 1.0 and 3.0 m a. s. l. and within the long-duration medium risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

Appendix E. Long-duration risk level maps for road and railway features.

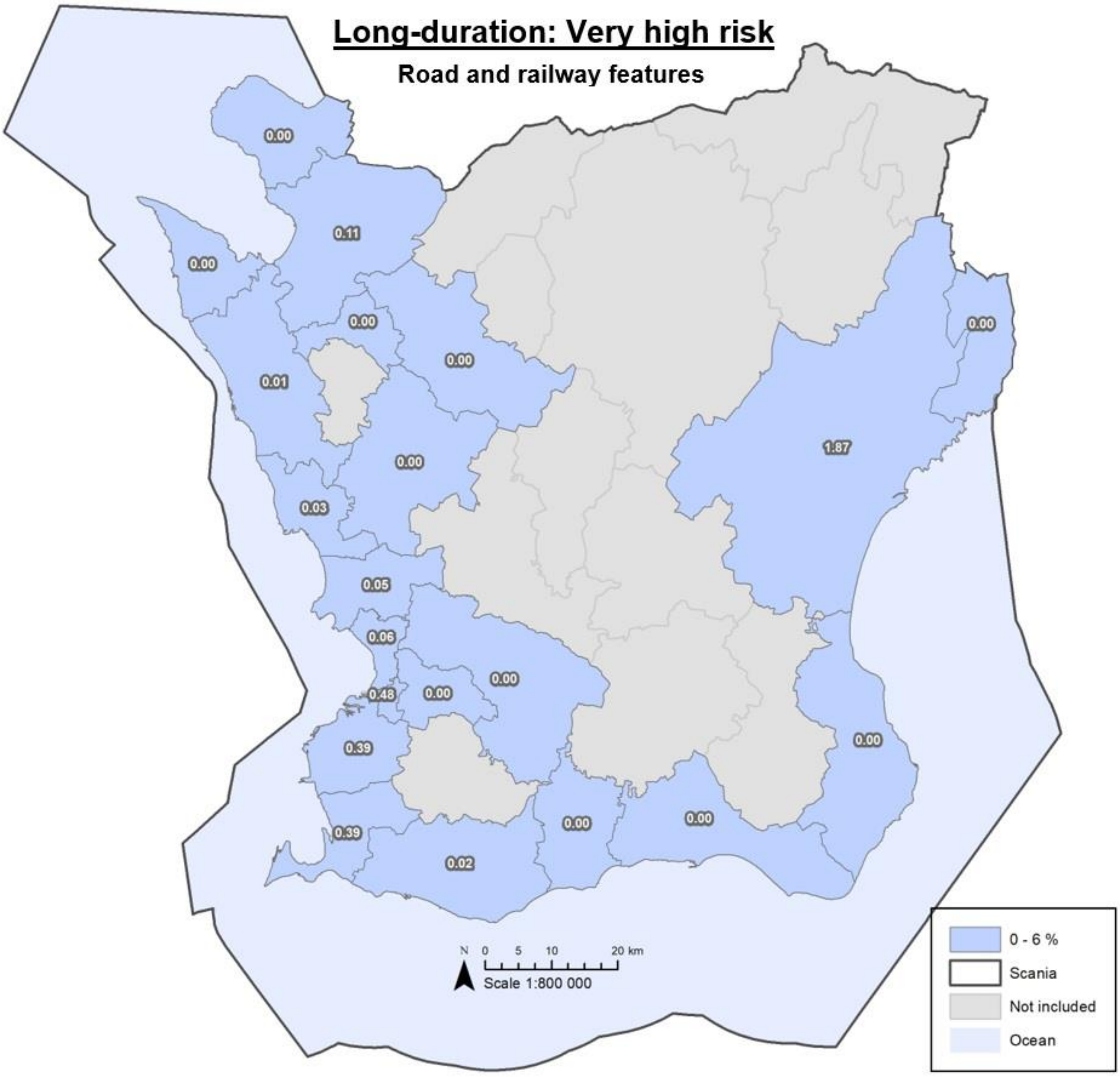

Figure E1. The average percentage of road and railway features positioned below 0.5 m a. s. l. and within the long-duration, very high risk level in each municipality.

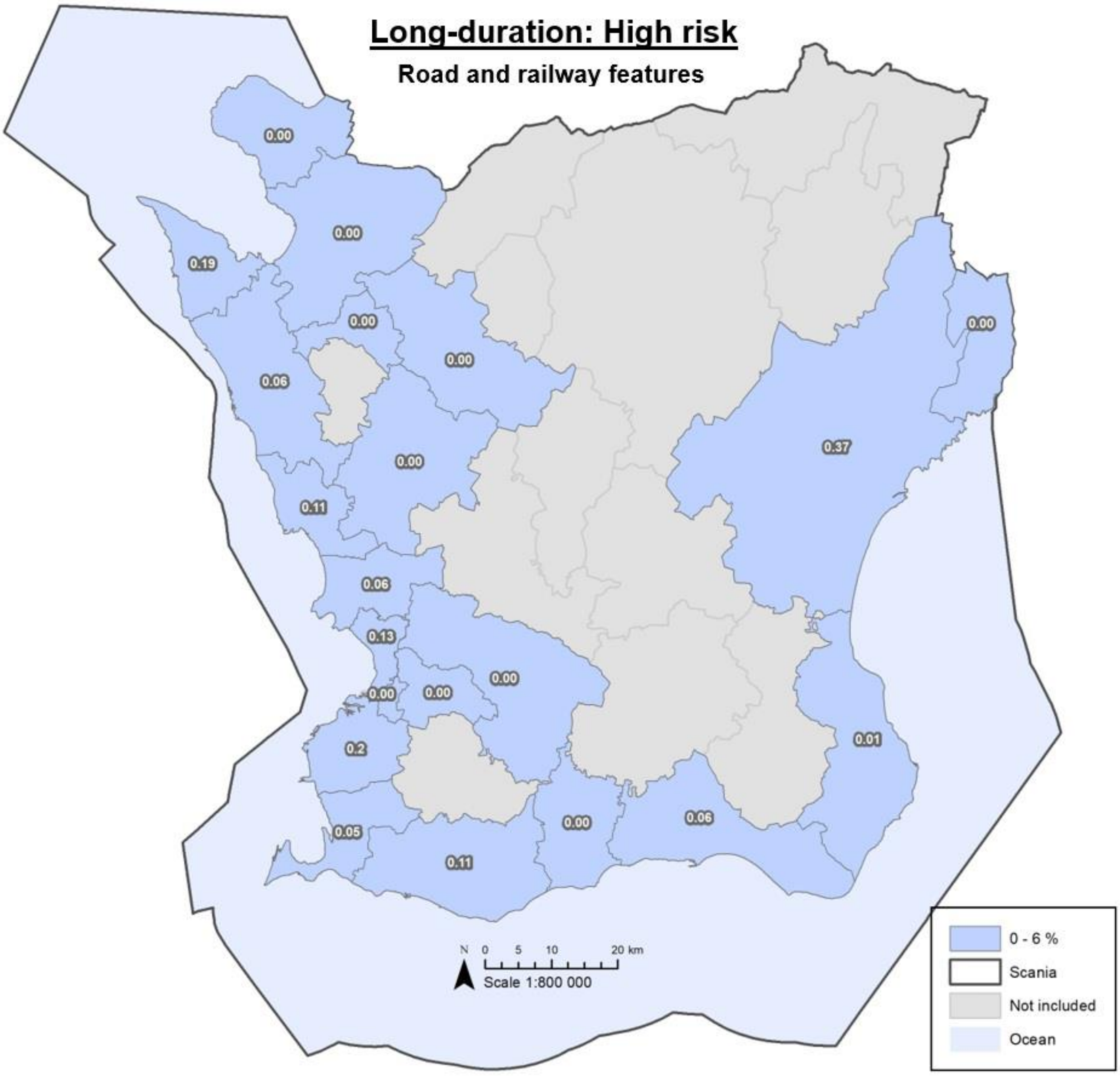

Figure E2. The average percentage of road and railway features positioned between 0.5 and 1.0 m a. s. l. and within the long-duration, high risk level in each municipality.

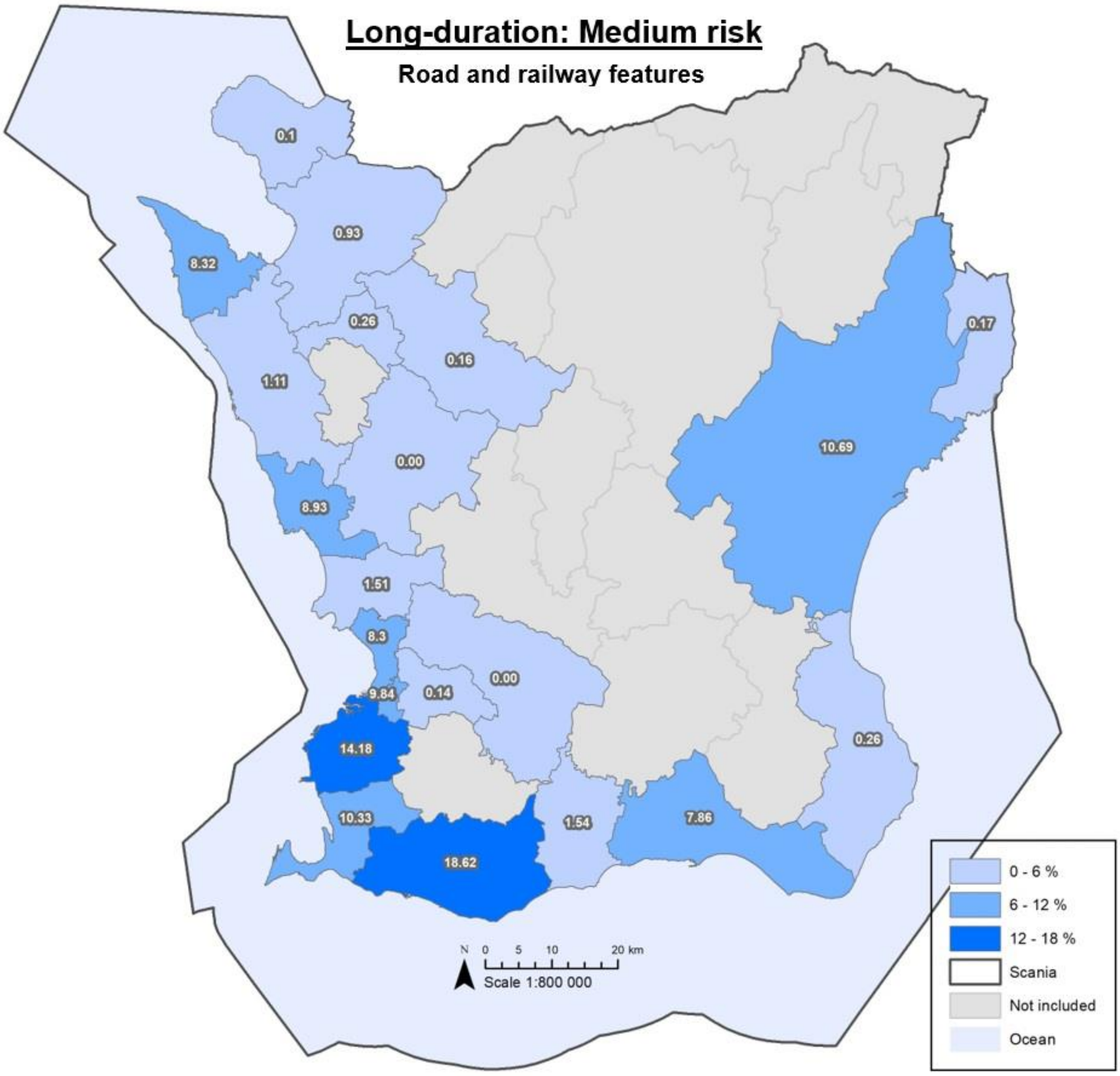

Figure E3. The average percentage of road and railway features positioned between 1.0 and 3.0 m a. s. l. and within the long-duration, medium risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

Appendix F. Short-duration risk level maps for environmental objects.

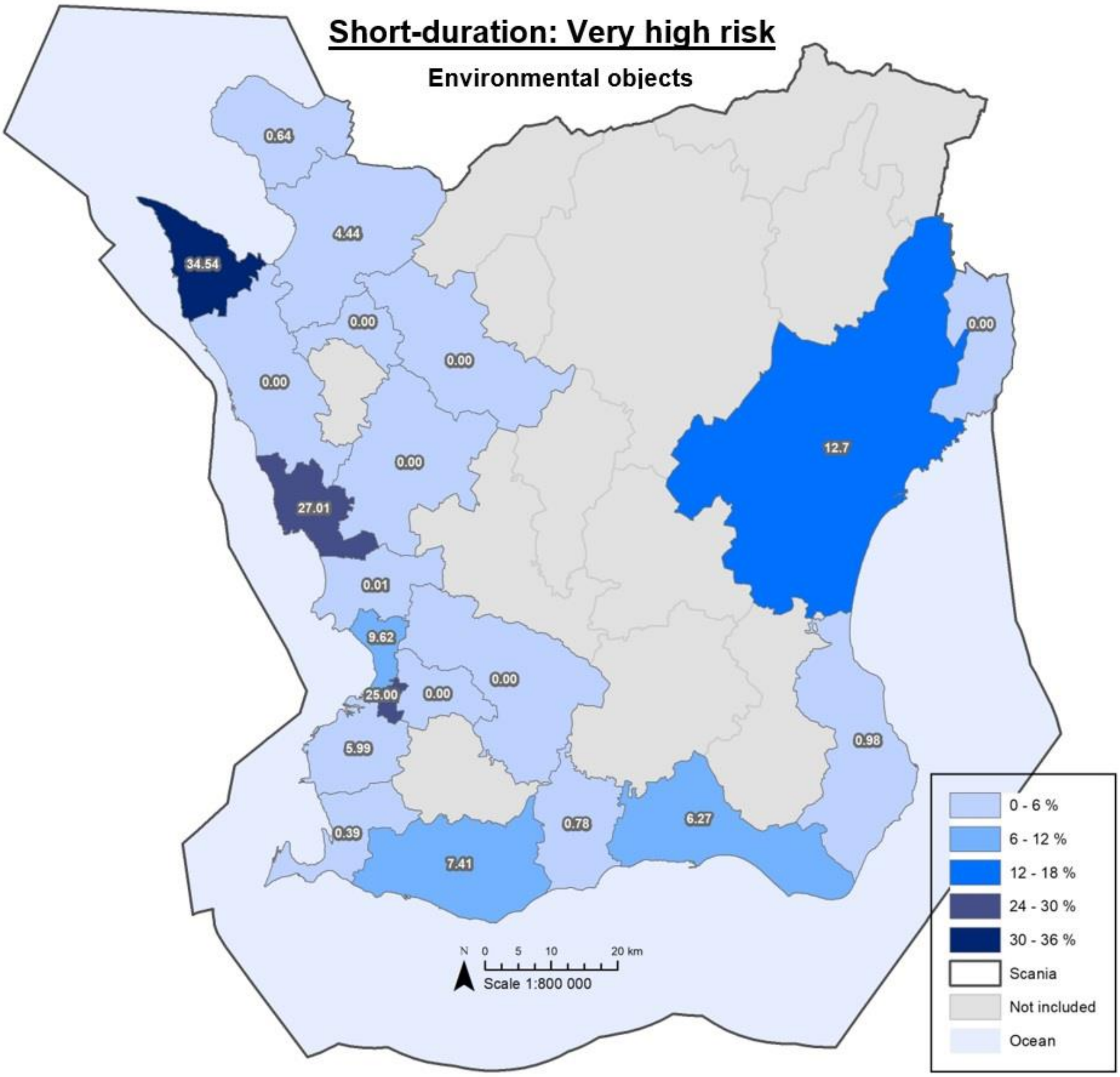

Figure F1. The average percentage of environmental objects positioned below 2.5 m a. s. l. and within the short-duration, very high risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

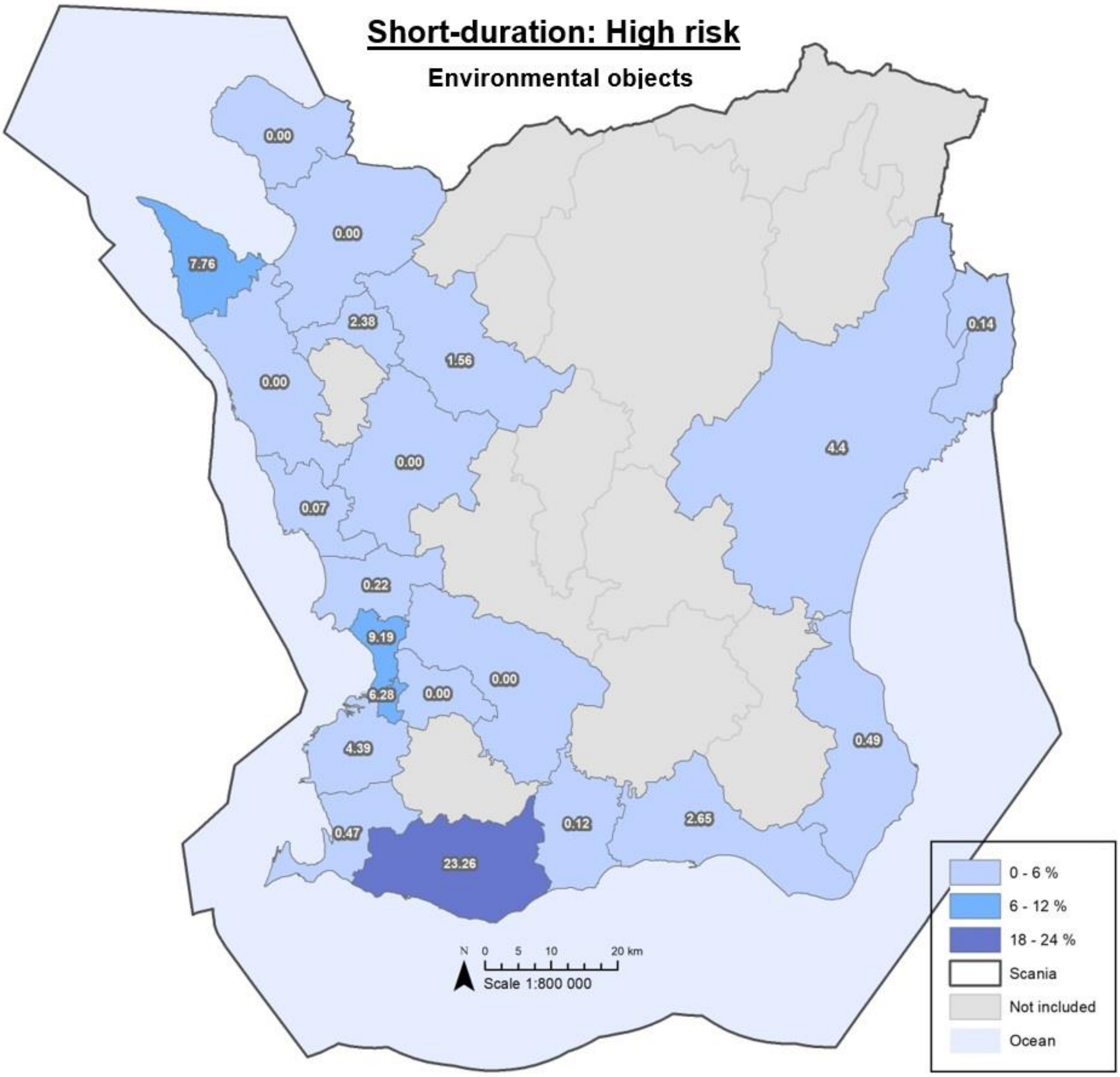

Figure F2. The average percentage of environmental objects positioned between 2.5 and 3.0 m a. s. l. and within the short-duration, high risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

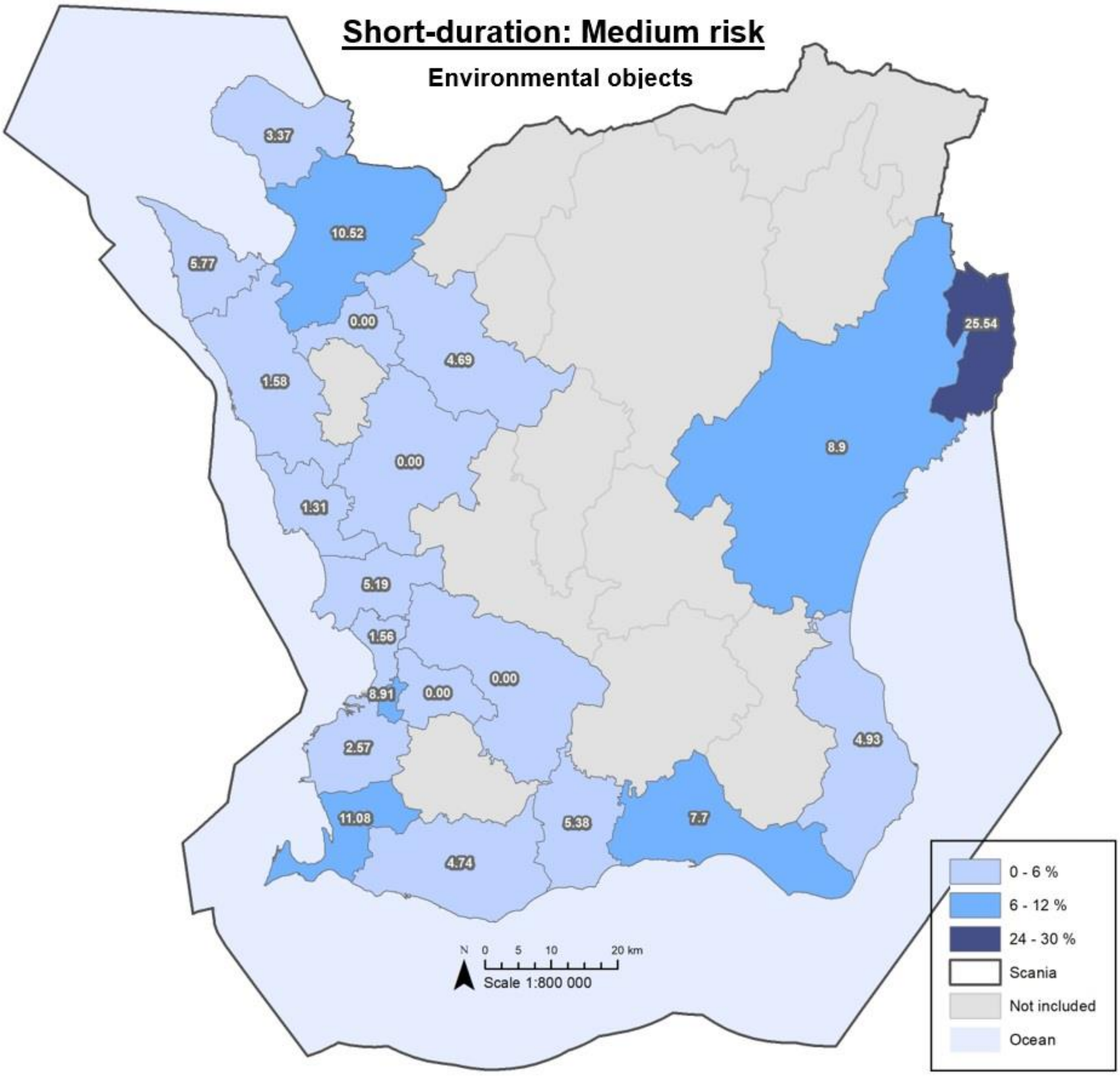

Figure F3. The average percentage of environmental objects positioned between 3.0 and 5.0 m a. s. l. and within the short-duration, medium risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

Appendix G. Short-duration risk level maps for road and railway features.

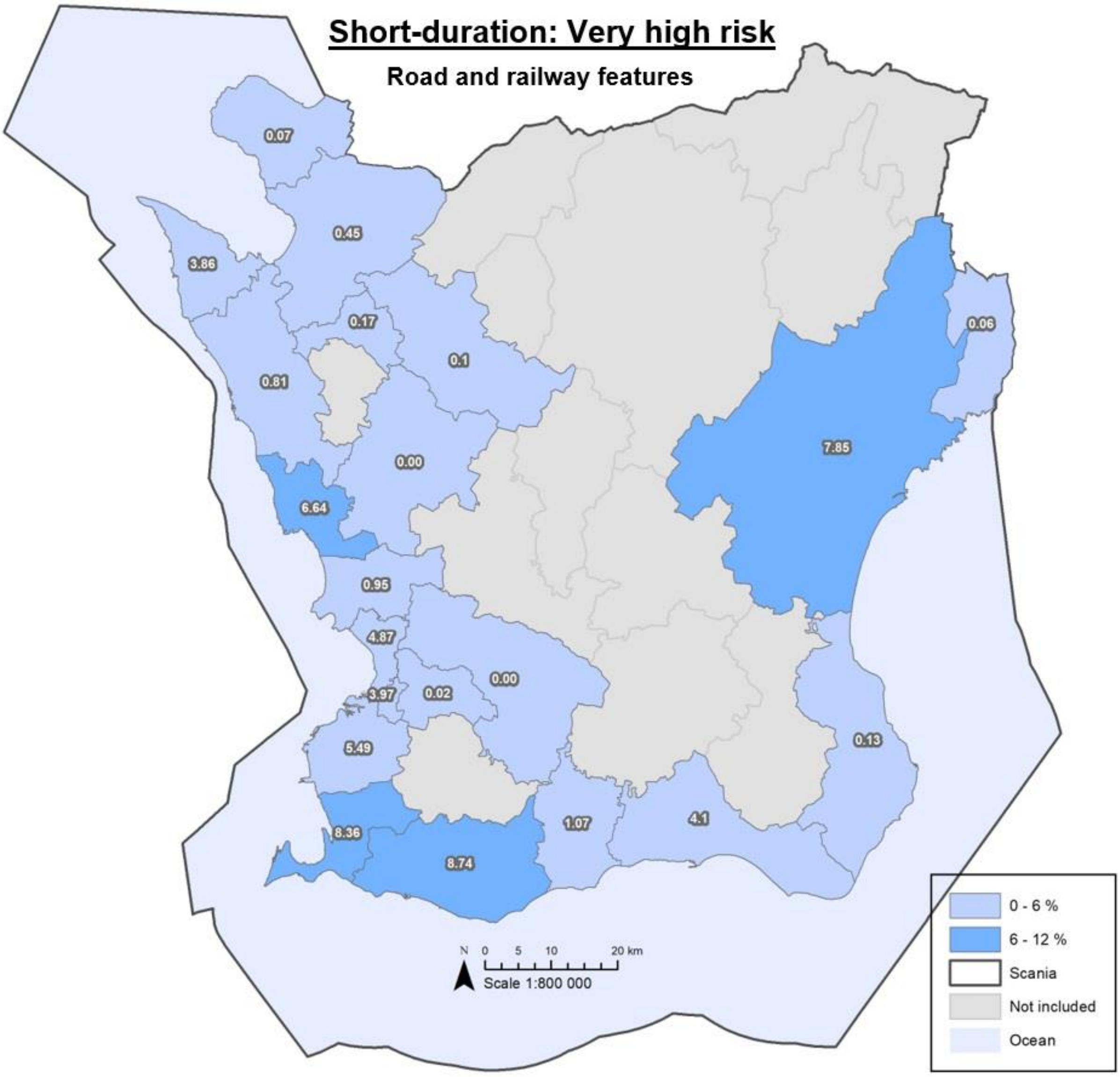

Figure G1. The average percentage of road and railway features positioned below 2.5 m a. s. l. and within the short-duration, very high risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

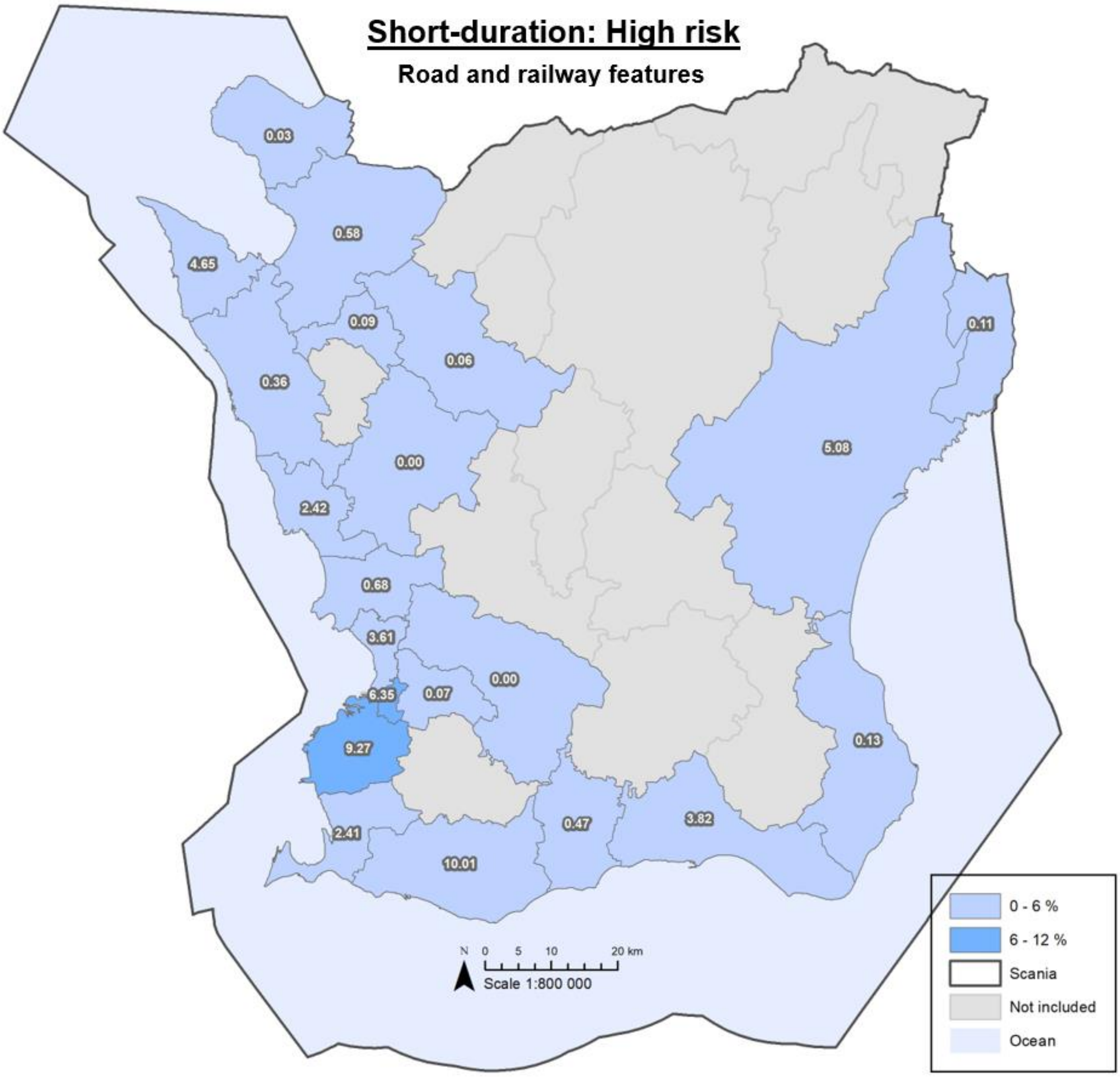

Figure G2. The average percentage of road and railway features positioned between 2.5 and 3.0 m a. s. l. and within the short-duration, high risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

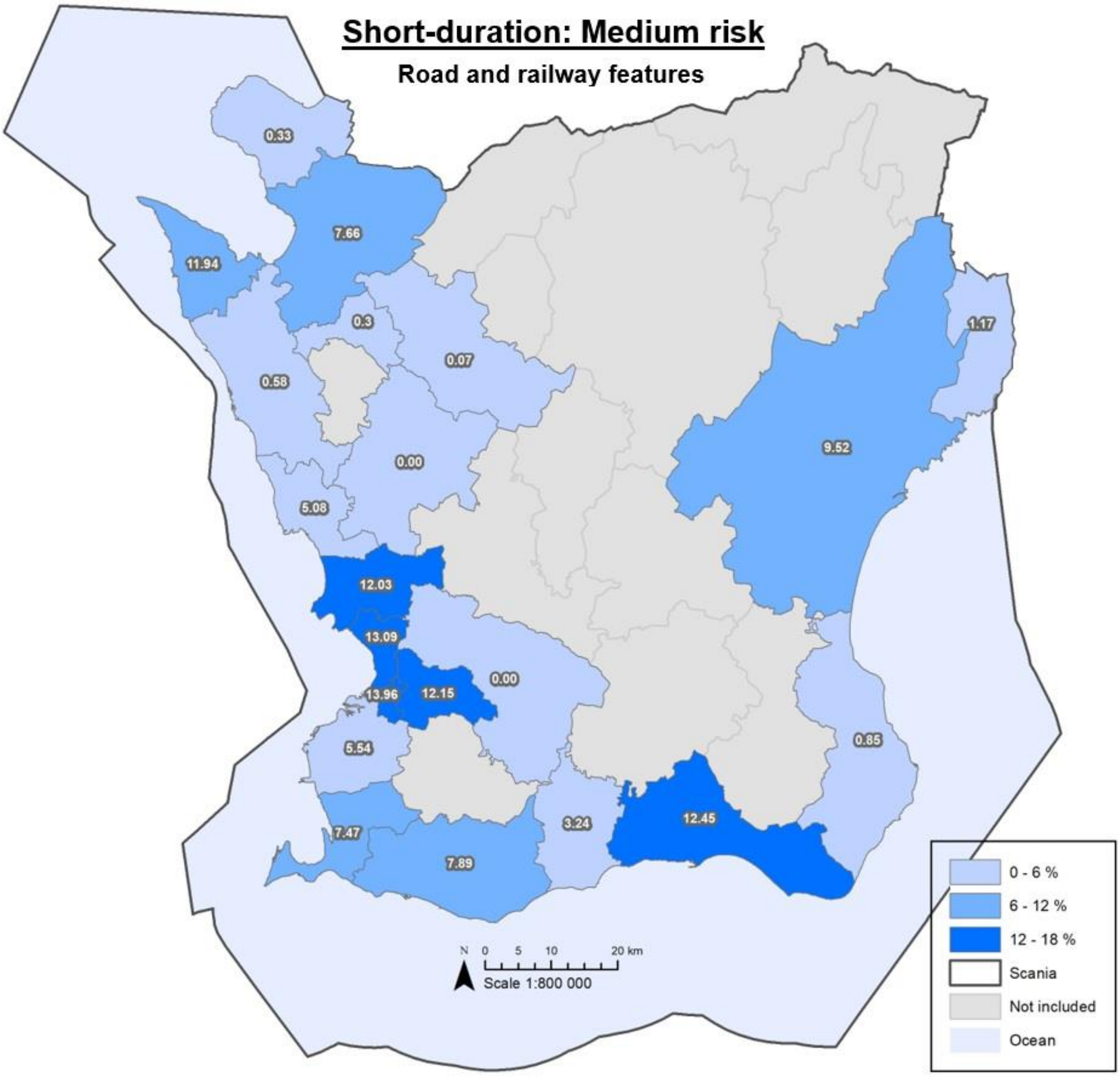

Figure G3. The average percentage of road and railway features positioned between 3.0 and 5.0 m a. s. l. and within the short-duration, medium risk level in each municipality. Light blue indicates lower percentages while dark blue indicates higher.

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