Research results of the CLINF Nordic Centre of Excellence

2016 - 2021

Climate change effects on the epidemiology of infectious diseases and the impacts on Northern societies

Photos: Carl-Johan Utsi

CLINF

NordForsk

What is it all about?

Climate change affects the Arctic more than any other part of the world.

The permafrost is thawing.

Traditional livelihoods are threatened by environmental changes.

Old and new infectious diseases might be emerging.

CLINF Objectives:

- To understand the impact of climate change on the distribution of infectious diseases in the North and thus on the socio-economic conditions, particularly for pastoralist communities.
- To turn this new understanding into practical tools for decision-makers.

Who are we?

Interdisciplinary research team

- Biologists
- Ecologists
- Economists
- Veterinarians
- Climatologists
- Social philosophers
- Human health experts
- Sociologists and anthropologists
- Mathematicians and bioinformaticians
- Experts on gender and traditional knowledge


Photo: T. Fagertun

UMEÅ UNIVERSITET

SLU

STATENS VETERINÄRMEDICINSKA ANSTALT

NORD University

NORCE

Stockholms universitet

FINNISH METEOROLOGICAL INSTITUTE

STATENS SERUM INSTITUT

Our starting point

The basic hypothesis:

The habitats of vector organisms for climate-sensitive infections (CSI) are expanding northwards.

The CLINF study region:

★ from Nuuk, western Greenland

★ to Yakutsk, eastern Siberia

Geographic CSI expansion (hypothetic)

What did we do?

- Compile data on human and animal diseases, on climate and on landscape, from Nuuk to Yakutsk.
- Identify CSI in the North.
- Forecast the future geographic spread of CSI in the North.
- Understand the societal impact of CSI and needs for adaptation.
- Create the CLINF Geographic Information System for public access to all CLINF data.

What are our results?

Here we are presenting some of our results in the form of short science stories that are sorted under the following headlines:

1 – Putative climate-sensitive infections in humans and animals

2 – Seroprevalence of putative CSI in humans and reindeer

3 – Prevalence of ticks and tick-borne pathogens

4 – Climate models for forecasting future CSI geographies

5 – Environmental envelopes affecting the prevalence of CSI

6 – Future CSI geographies

7 – Impact of CSI on northern societies

8 – Adaptation strategies for pastoralists in the North

CLINF

NordForsk

The CLINF Geographical Information System – CLINF GIS

We have compiled three types of openly available data, all covering the same 30 year-climate reference period (1985-2016):

- Historical incidence data for more than 30 animal and human infectious diseases from national registers throughout the CLINF study region,
- Satellite data products for meteorological and hydrological variables (“weather”), and
- Satellite data products for landcover variables such as the density of chlorophyll (“greening”).

These data were standardized to fit the same spatial and temporal scale. Then we used the landscape and climate data to statistically explain changes in the geographical distribution of CSI.

These statical models then also allow to forecast future geographies of CSI in the Arctic.

All data is freely available at www.clinf.org. Look for the CLINF GIS Public Data Repository !

Chapter 1:
Putative climate-sensitive infections in humans and animals

There are plenty of infectious diseases that may affect humans and animals in the Arctic region.

Many of them may be transferred from animals to humans, so-called zoonoses.

Many infectious diseases are transferred by vector organisms such as ticks or mosquitoes.

The question is, which of these infectious diseases respond to climate change? Which infections are more likely to occur in the future?

Putative climate-sensitive infections

- Anaplasmosis
- Anthrax
- Babesiosis
- Borreliosis
- Brucellosis
- Cryptosporidiosis
- Elaphostrongylus rangiferi
- Fascioliosis
- Hemorrhagic fever with renal disorder
- Leptospirosis
- Necrobacilliosis
- Parapoxvirus
- Pestivirus
- Rickettsioses
- Q-fever
- Tick-borne encephalitis (TBE)
- Tularemia
- West Nile Fever

Indications of CSI from the scientific literature (1)

Our systematic literature study of reports on infectious diseases in the CLINF study region shows:

- Mainly arthropod vector-borne diseases seem to have the potential to expand towards northern latitudes.
- **Tick-borne encephalitis (TBE)** and **borreliosis**, **midge-borne bluetongue** and the parasitic infection **fasciolosis** can be classified as climate-sensitive.

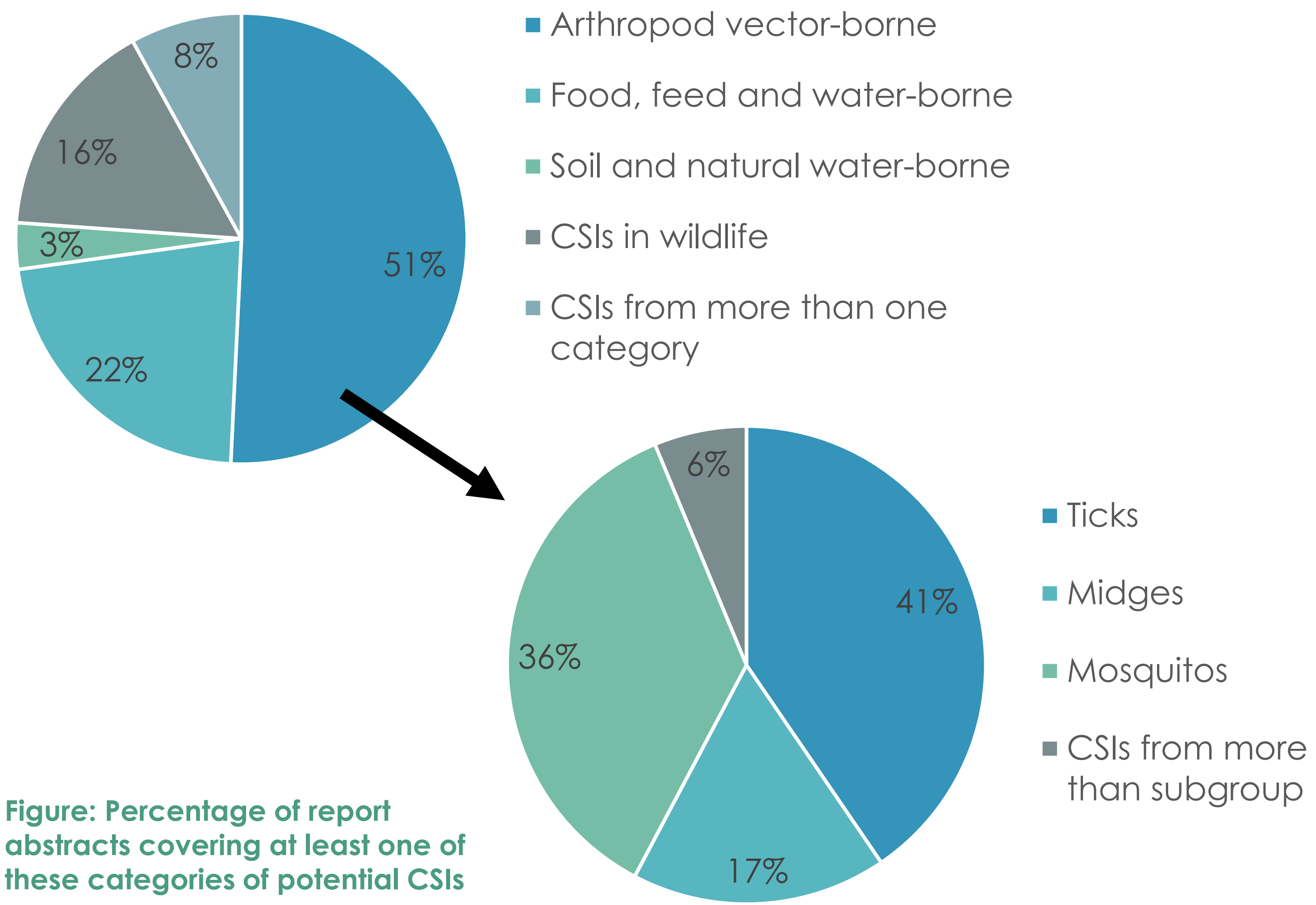


Figure: Percentage of report abstracts covering at least one of these categories of potential CSIs

Indications of CSI from the scientific literature (2)

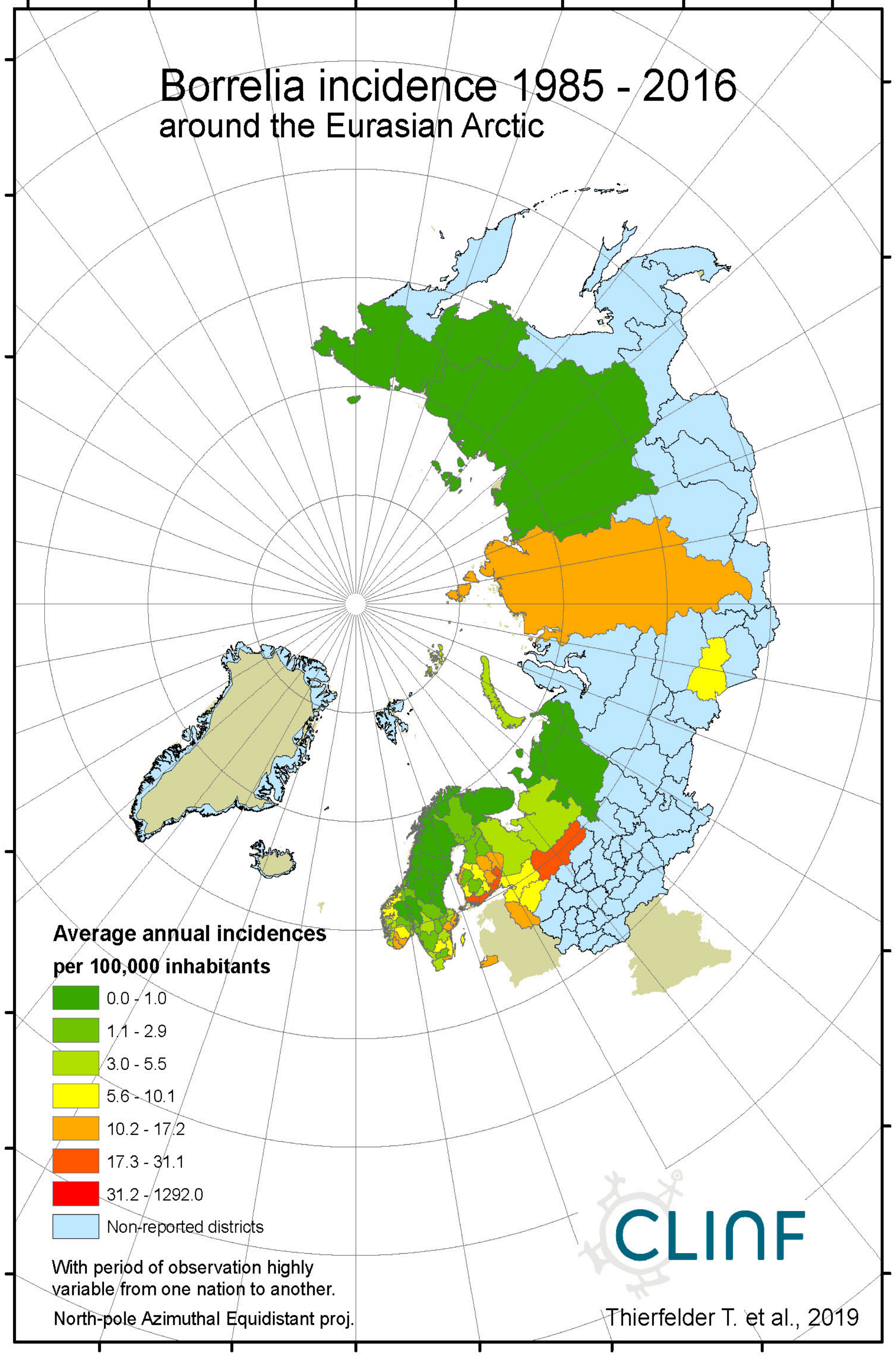
We identified **TBE, borreliosis, bluetongue** and **fasciolosis** as likely being climate-sensitive.

We suggest that in northern regions these CSI should be monitored in a systematic surveillance programme.

Climate change may affect the epidemiology and geographical range of many more infectious diseases. But, in our literature study, we could not clearly identify additional CSI. This is most likely because other factors might be of equal or even greater importance than climate change.

However, climate-ecological dynamics are constantly changing. Diseases may fall in or out of the CSI definition with time. Scholars are increasingly becoming aware of the effects of climate change on infectious diseases.

Omazic et al. (2019) Acta Vet. Scand. 61:53; https://doi.org/10.1186/s13028-019-0490-0



Moving CSI geographies – The example of borreliosis (1)

Based on CLINF GIS data we found that **borreliosis, Q-fever**, **tick-borne encephalitis** and **tularemia** have significantly responded to the warming of northern landscapes.

Example of the maps and map-like animations of observed and predicted geographic scenarios of CSI distribution as available in CLINF GIS (www.clinf.org).

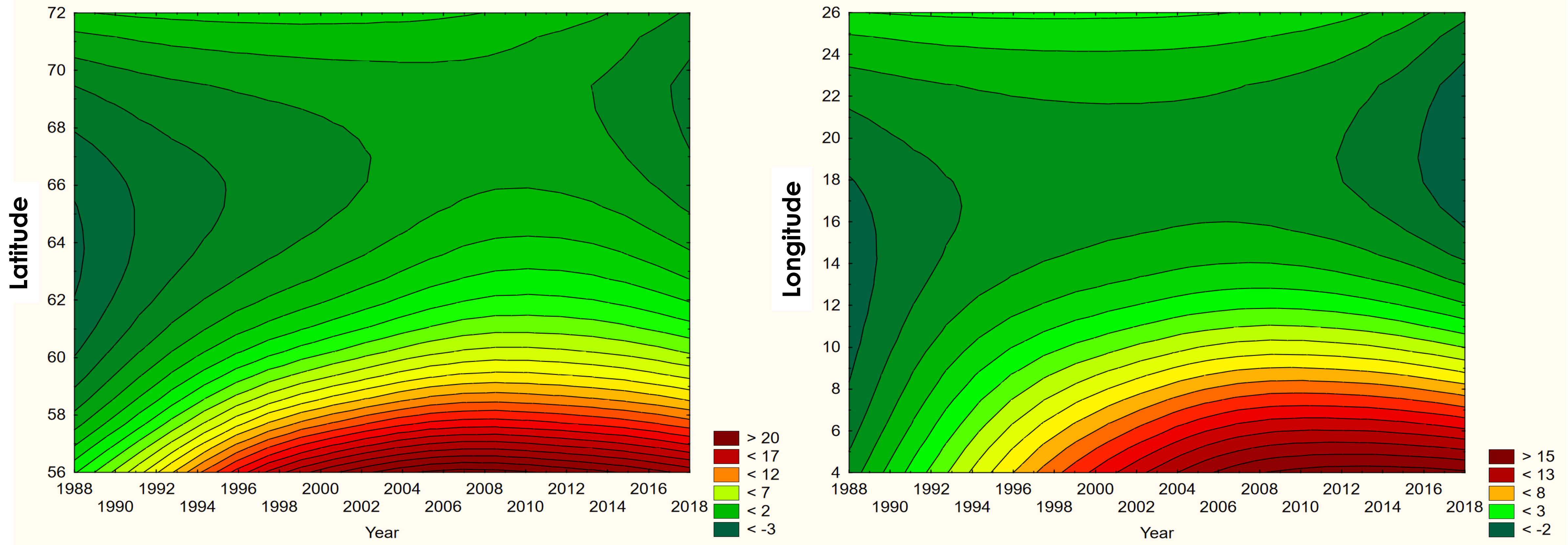
Figure: Average annual borreliosis incidences per 100 000 inhabitants in the CLINF study region throughout the 30 year-climate reference period. Borreliosis incidences were extremely high at the Finnish/Baltic archipelago of Ahvenanmaa (Aland).

Thierfelder et al., manuscript in preparation Feb 2021: The geography of northern infectious diseases, with particular emphasis on climate change effects.

NordForsk

Moving CSI geographies – The example of borreliosis (2)

The geographical distribution of **borreliosis** in Norway has moved northwards along the coastline and at the same time protruded inlands.



Figures: Borreliosis incidence per 100 000 inhabitants in Norway throughout the 30 year-climate reference period. Third-degree spline interpolations, including interpolation artefacts (like negative incidences).

CLINF

Thierfelder et al., manuscript in preparation Feb 2021: The geography of northern infectious diseases, with particular emphasis on climate change effects.

NordForsk

Chapter 2: Seroprevalence of putative CSI in humans and reindeer

After having recovered from an infection antibodies against the pathogen circulate in the blood stream of humans and animals for a long time.

This fact can be exploited to investigate how wide-spread an infectious disease is in a given population.

Seroprevalence data supplements the clinical data that is recorded in the national diseases registers and that we have compiled in CLINF GIS.

Seroprevalence of seven CSI in Greenland and northern Sweden (1)

An analysis of serum samples from Greenland and northern Sweden demonstrates for the first time the presence of seropositivity to **brucellosis, leptospirosis, rickettsioses** and **tularemia** in Greenland, even if the figures for brucellosis and tularemia were as low as 1% of the tested samples.

In West Greenland, the percentage of **leptospirosis** positive samples increased significantly from 2.5% in 1998 to 30% in 2013.

Our findings provide new baseline data for human seroprevalence of rarely or not at all described CSI in Greenland and northern Sweden.

CLINF

Authored by Koch et al., manuscript in preparation Feb 2021.

NordForsk

Seroprevalence of seven CSI in Greenland and northern Sweden (2)

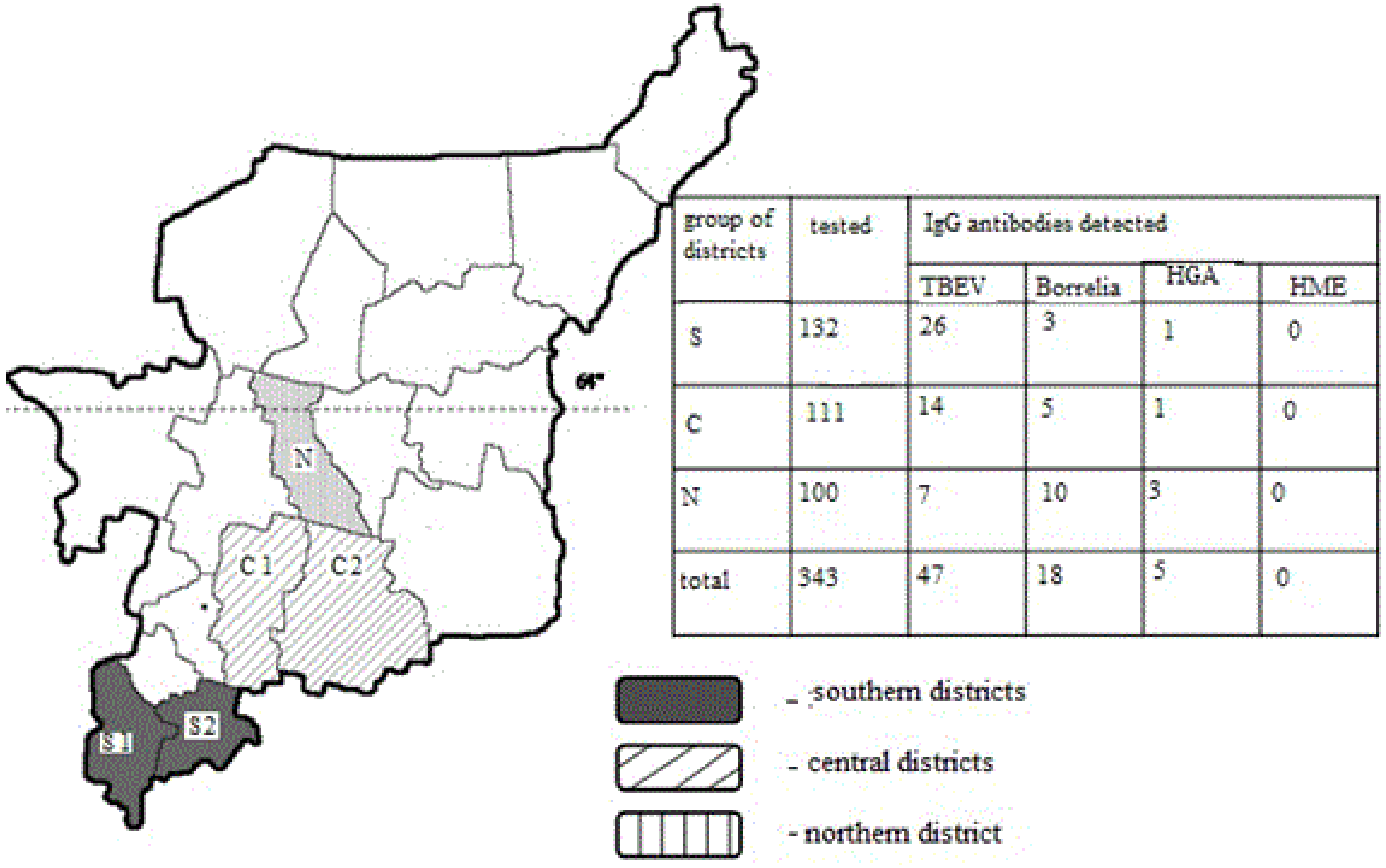
Table: Percentage of serum samples that tested positive against seven CSI. Stored serum samples from 50 years-old donors from Greenland (460 in total) and Umeå region in northern Sweden (200 in total) were tested. The year of sampling is indicated.

Putative CSI	Greenland 1998	Greenland 2013	northern Sweden 2012-2017
Brucellosis	Not tested	1%	1%
Leptospirosis	2.5%	21%	4%
Q-fever	Not tested	Not detectable	Not detectable
Rickettsioses	12.5%	9%	11.5%
Tularemia	Not tested	1%	3%
Borreliosis	Not tested	Not tested	2%
TBE	Not tested	Not tested	5%

Tick-borne diseases in the European North of Russia (1)

We analyzed blood samples from healthy donors for the presence of antibodies against several tick-borne diseases.

- For the first time we detected the putative CSI human **granulocytic anaplasmosis** in Komi Republic.
- 20% of the samples tested positive for tick-borne diseases indicating a wide distribution in the region.
- We found a significant increase in **TBE** between 2001 and 2013 (see next page).



group of districts	tested	IgG antibodies detected			
		TBEV	Borrelia	HGA	HME
S	132	26	3	1	0
C	111	14	5	1	0
N	100	7	10	3	0
total	343	47	18	5	0

Figure: Map of Komi Republic with administrative division. Number and geographic distribution of blood samples from healthy donors (aged 20-70) that were positive for antibodies against tick-borne encephalitis virus (TBEV), borrelia, human granulocytic anaplasmosis (HGA) and human monocytic ehrlichiosis (HME) in 2013.

Tick-borne diseases in the European North of Russia (2)

Table: Occurrence and geographic distribution of samples positive for antibodies against TBE virus in Komi Republic in 2001 and 2013.

Districts	2001		2013		Criteria
	positive/tested	% ± m	Positive/tested	% ± m	t and p
S	10/264	3.8 ± 1.2	23/132	19.7 ± 3.5	4.3; p<0.001
S1	5/145	3.4 ± 1.5	20/102	19.6 ± 3.9	3.9; p<0.001
S2	5/119	4.2 ± 1.8	6/30	20.0 ± 4.0	3.6; p<0.001
C	8/233	3.4 ± 1.2	14/111	12.6 ± 3.1	2.8; p<0.05
C1	4/108	3.7 ± 1.8	10/81	12.3 ± 3.6	2.1; p<0.05
C2	4/125	3.2 ± 1.6	4/30	13.3 ± 3.4	2.7; p<0.05
N	3/100	3.0 ± 1.7	7/100	7.0 ± 2.6	1.3; p>0.05
Total	21/597	3.5 ± 0.75	47/343	13.7 ± 1.9	5.1; p<0.001

S-Southern districts: S1-Priluzskiy; S2-Koigorodskiy
C-Central districts: C1-Ust-Kulomskiy; C2-Kortkerosskiy
N-Northern district: Intinskiy

Our results indicate an increasing risk for **TBE** in Komi Republic, including areas, where this disease has not been recorded previously. These findings justify the need to improve the diagnostic methods for tick-borne infections, epidemiological countermeasures and education of the local population on how to avoid such infections.

Tokarevich et al. (2017) Medical Safety & Global Health 6:1; https://doi.org/10.4172/2574-0407.1000132

Pestivirus in reindeer

Pestivirus infection can lead to serious health problems in ungulates and cause considerable economic loss for the livestock industry. Several types of pestivirus can transmit between different host animal species.

We analyzed blood samples of Eurasian tundra reindeer for the presence of CSI pathogens.

Our study confirmed the circulation of pestivirus in reindeer from Finland, Sweden and Norway. For the first time, pestivirus was also detected in reindeer from Iceland.

The type of the reindeer pestivirus is still unknown, as is the clinical relevance of pestivirus infection in reindeer. There is no evidence that the status of Pestivirus D infection in cattle in a geographical area has any influence on pestivirus prevalence in reindeer.

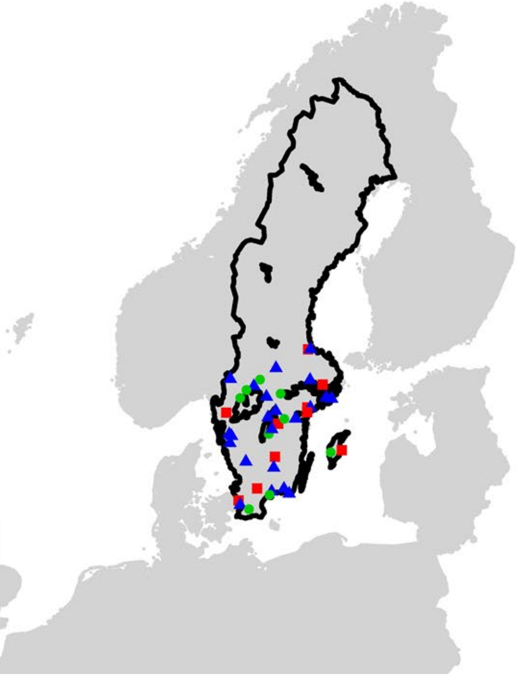
Chapter 3:
Prevalence of ticks and tick-borne pathogens

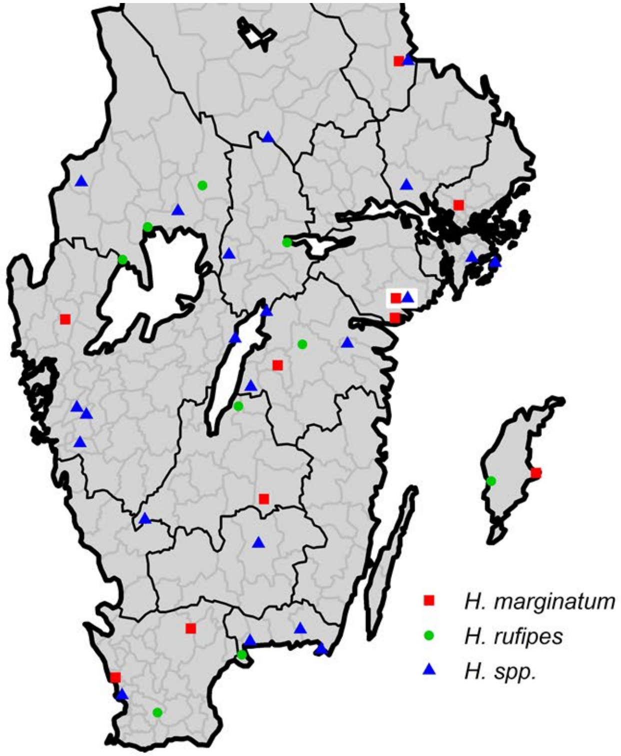
Many infectious diseases are transmitted by blood-feeding vector organisms such as mosquitoes or ticks.

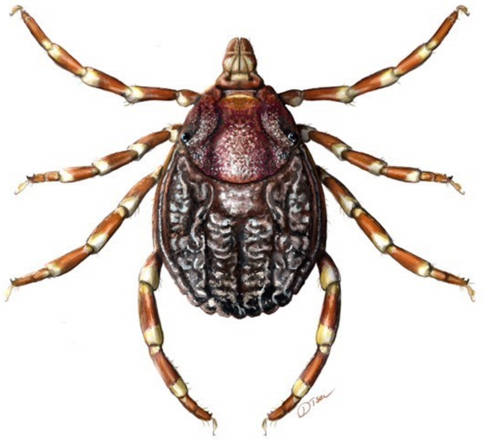
Well-known examples are malaria, tick-borne encephalitis (TBE) and Lyme disease.

Monitoring the prevalence of vector organisms in nature as well as their pathogen load can helps us assess the risk of disease transmission in a given area.

First records of adult *Hyalomma* ticks in Sweden







Figures: Top: *Hyalomma* ticks found in Sweden from July 2018 to January 2019. *H.spp*. means either *H. marginatum* or *H. rufipes*, based on photographs.

Bottom: *Hyalomma marginatum*, illustration by Disa Eklöf, National Veterinary Institute

Our citizen science study yielded 41 specimens of adult *Hyalomma* ticks, which had been found on horses, cattle or humans. *Hyalomma* ticks had previously only rarely been found in Sweden and then only at immature stages.

The rapidly changing climate in northern Europe seems to permit these tick species now to develop to adulthood.

Molecular testing of 20 ticks for Crimean-Congo haemorrhagic fever virus and for piroplasms (*Babesia* spp. and *Theileria* spp.) proved negative; but 12 ticks tested positive for **rickettsiae**.

We see a need to revise the risk maps for the potential geographic occurrence of ticks and tick-borne infections in Sweden and the neighboring countries.

Grandi et al. (2020) Ticks and Tick-borne Diseases 11:101403; https://doi.org/10.1016/j.ttbdis.2020.101403

NordForsk

Expanding tick habitat in the European North of Russia (1)

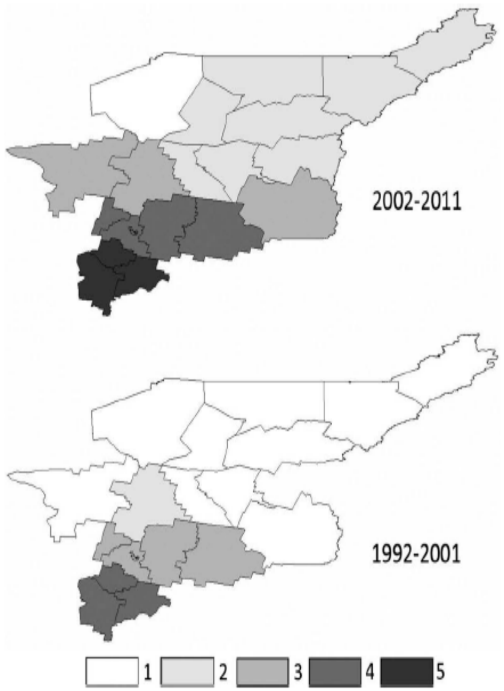


Figure: Tick-bite incidence rate in Komi Republic districts in 2002-2011 and 1992-2001. 1: <0,1; 2: 0,1-10; 3: 10-100; 4: 100-1000; 5: >1000.

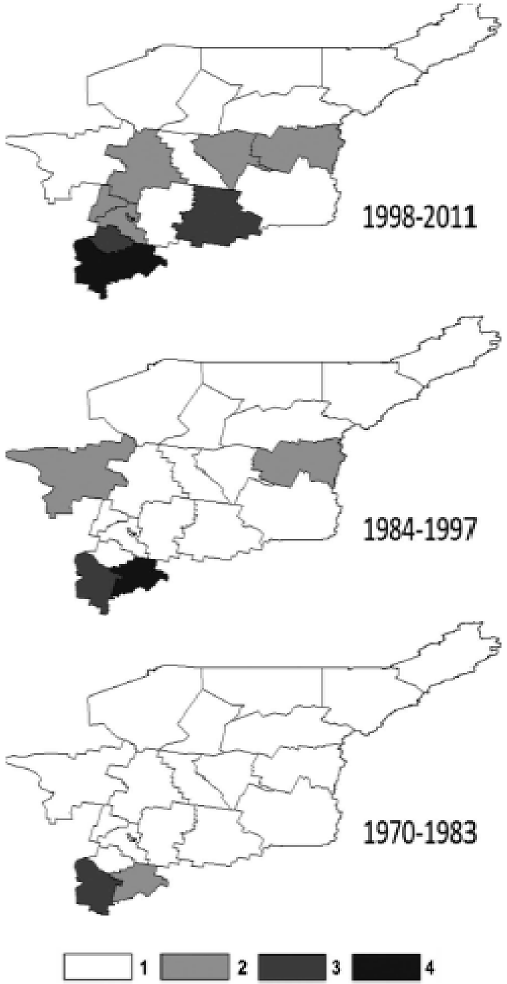


Figure: TBE incidence rate in Komi Republic districts for 14-year periods. 1: <0,099; 2: 0,1-0,99; 3: 1-4,99; 4: >5.

From 1998–2011 we observed a substantial increase in **TBE** virus both in questing and in feeding ticks in Komi Republic, Russia. The average annual incidence rate of TBE was >6-fold higher than during previous periods.

We found a 23-fold increase in the tick-bite incidence rate in humans, a northward shift of the reported tick bites, and an increase in the tick bite season from 4 to 6 months.

The increase in TBE correlated with the expanding range of *Ixodes persulcatus* ticks. The territory with reported cases of TBE expanded northwards.

Tokarevich et al. (2017) Intl. J. Circumpolar Health 76:1298882; https://doi.org/10.1080/22423982.2017.1298882

Chapter 4:
Climate models for forecasting future CSI geographies

Various climate models exist, each with a specific focus.

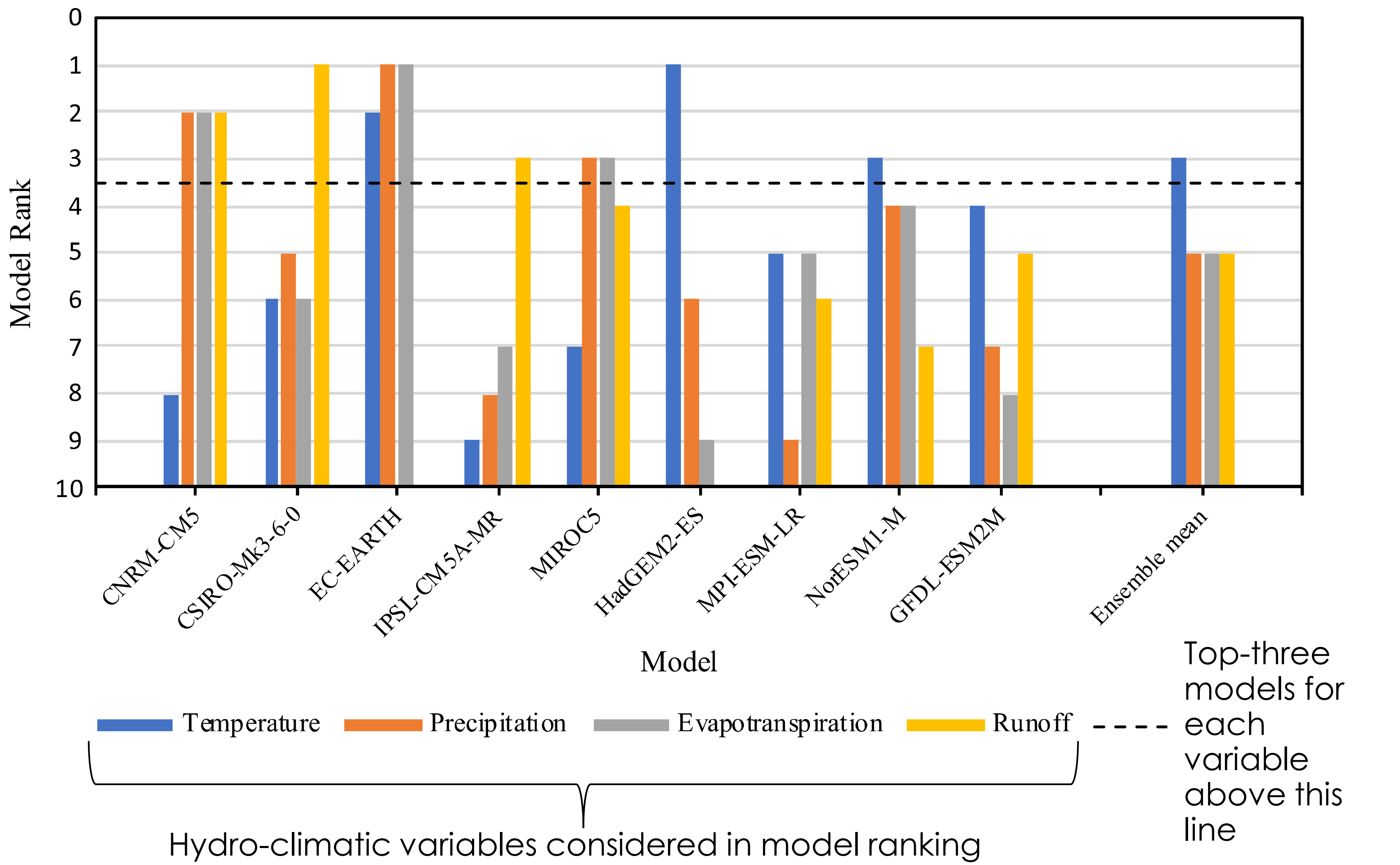
In order to produce reliable forecasts of future CSI geographies it is important to understand the strengths and weaknesses of these different models.

How reliably can the interactions between climate and landscape variables be projected?

Earth system model performance for hydro-climatic change in the Nordic-Arctic region

We evaluated the performance of climate models relative to observations for 64 Nordic and Arctic hydrological catchments:

- Model-observation agreement is similar for *Runoff* and *Temperature*, and distinctly higher than that for *Precipitation* or *Evapotranspiration*.
- Model projections for large- average *Runoff* are more or less similarly reliable as for large-scale average *Temperature*.



Bring et al. (2019) Earth's Future 7:1270-1282; https://doi.org/10.1029/2019EF001296

Permafrost-thaw effects pathogen mobilization and water-related spreading pathways

We simulated permafrost-thaw for different local soil conditions and large-scale surface-warming trends:

- Robust simulation results show strong thaw evolution dependence on the local soil conditions – in addition to the surface-warming trends.
- Potentially severe consequences of permafrost-thaw for mobilization and spreading of previously frozen pathogens in both peatlands and mineral soils.

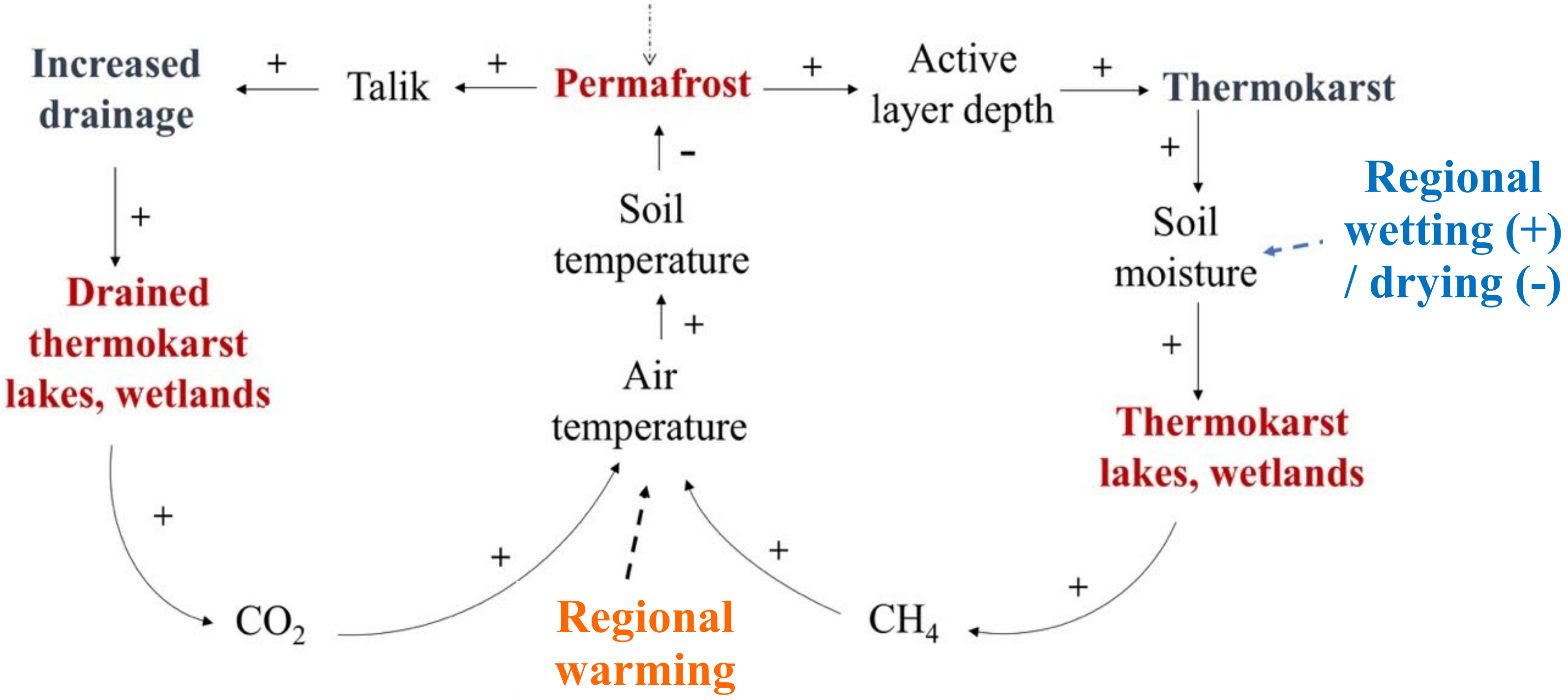
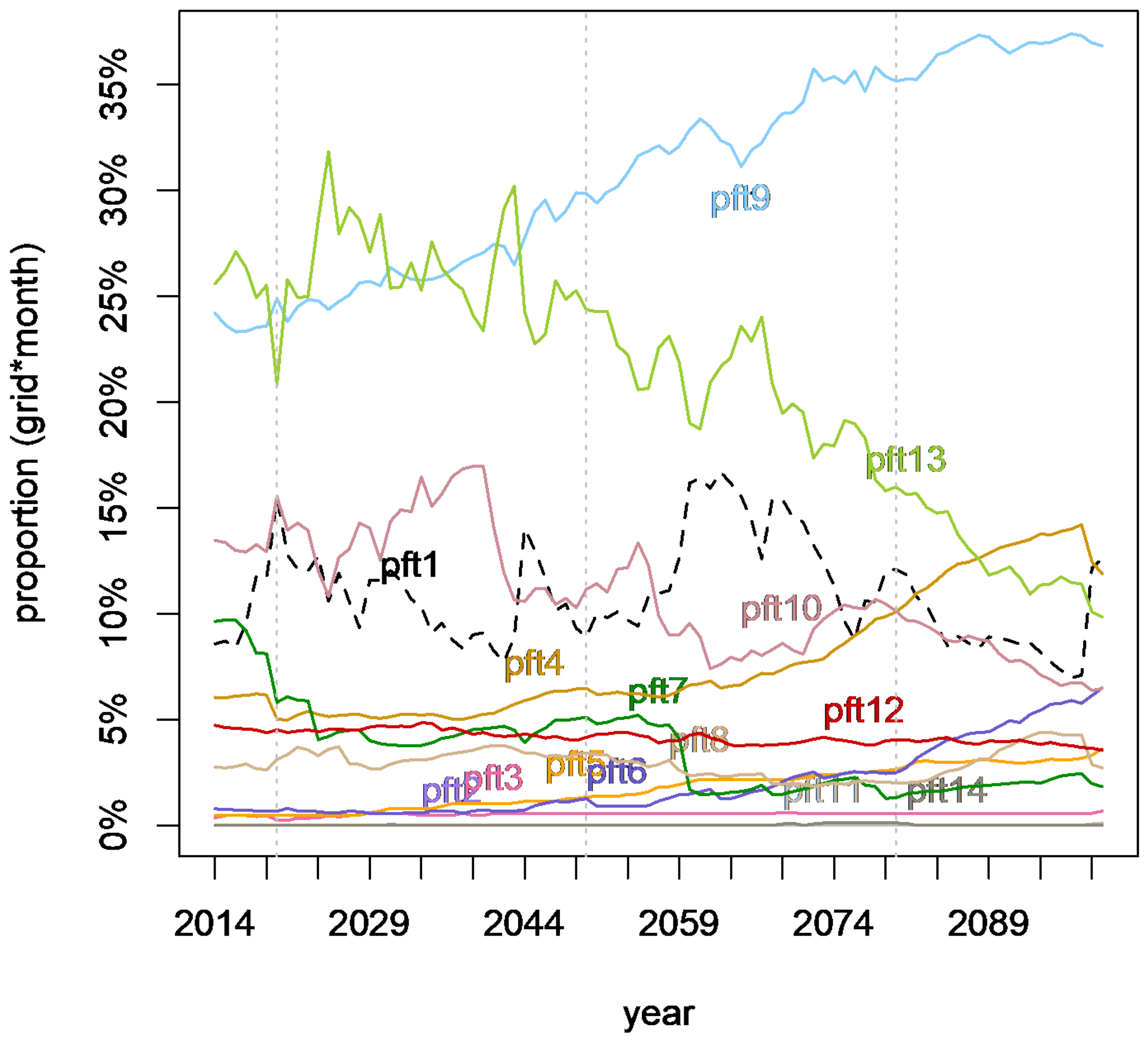


Figure: Bifurcation in wetland/lake evolution and feedbacks depending on extent of permafrost thaw

Projected land cover change in the 21rst century (1)



1 bare ground	2 tropical broadleaf evergreen
3 tropical broadleaf raingreen	4 temperate needleleaf evergreen
5 temperate broadleaf evergreen	6 temperate broadleaf summergreen
7 boreal needleleaf evergreen	8 boreal broadleaf summergreen
9 boreal needleleaf summergreen	10 C3 grass
11 C4 grass	12 NonVascular moss&lichen
13 boreal broadleaf shrubs	14 C3 arctic grass

Figure: Temporal evolution of 14 plant functional types (pft) throughout the 21rst century

CLINF

Leibovici & Claramunt (2019) Entropy 21:1112; https://doi.org/10.3390/e21111112

NordForsk

Projected land cover change for the 21rst century (2)

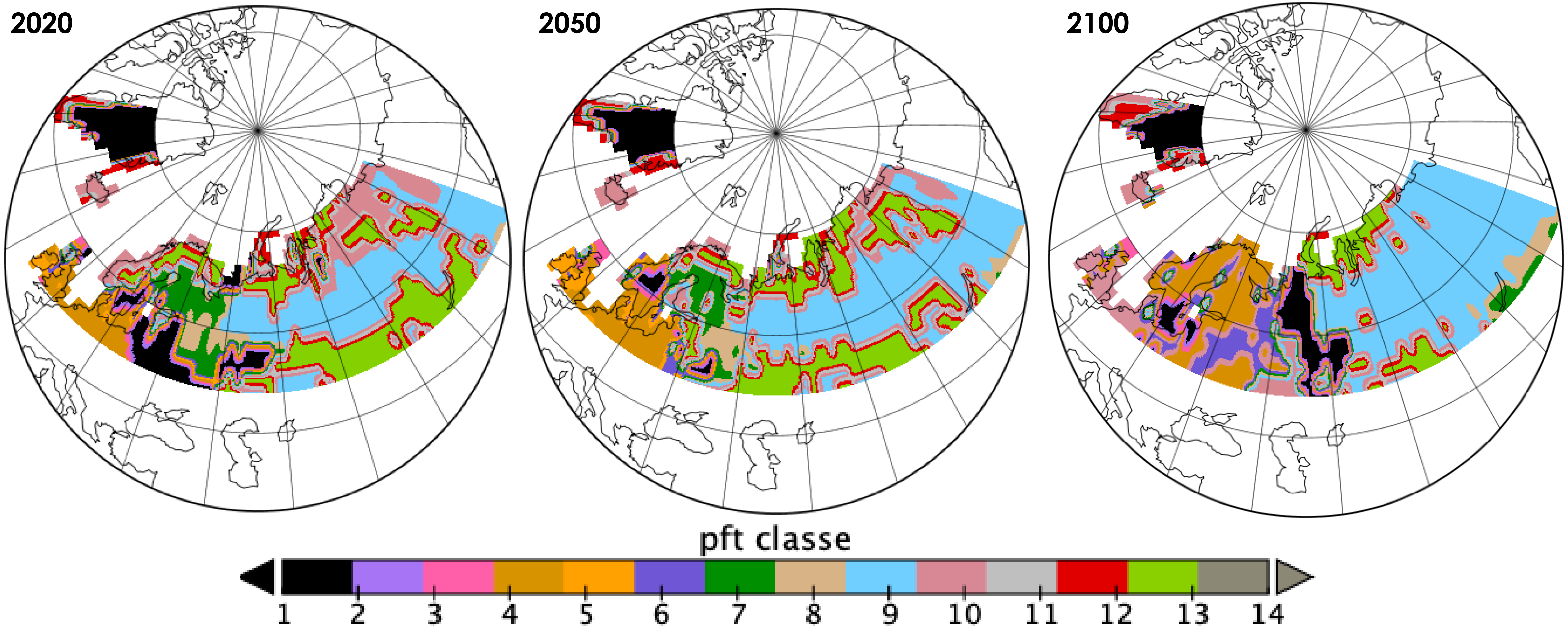


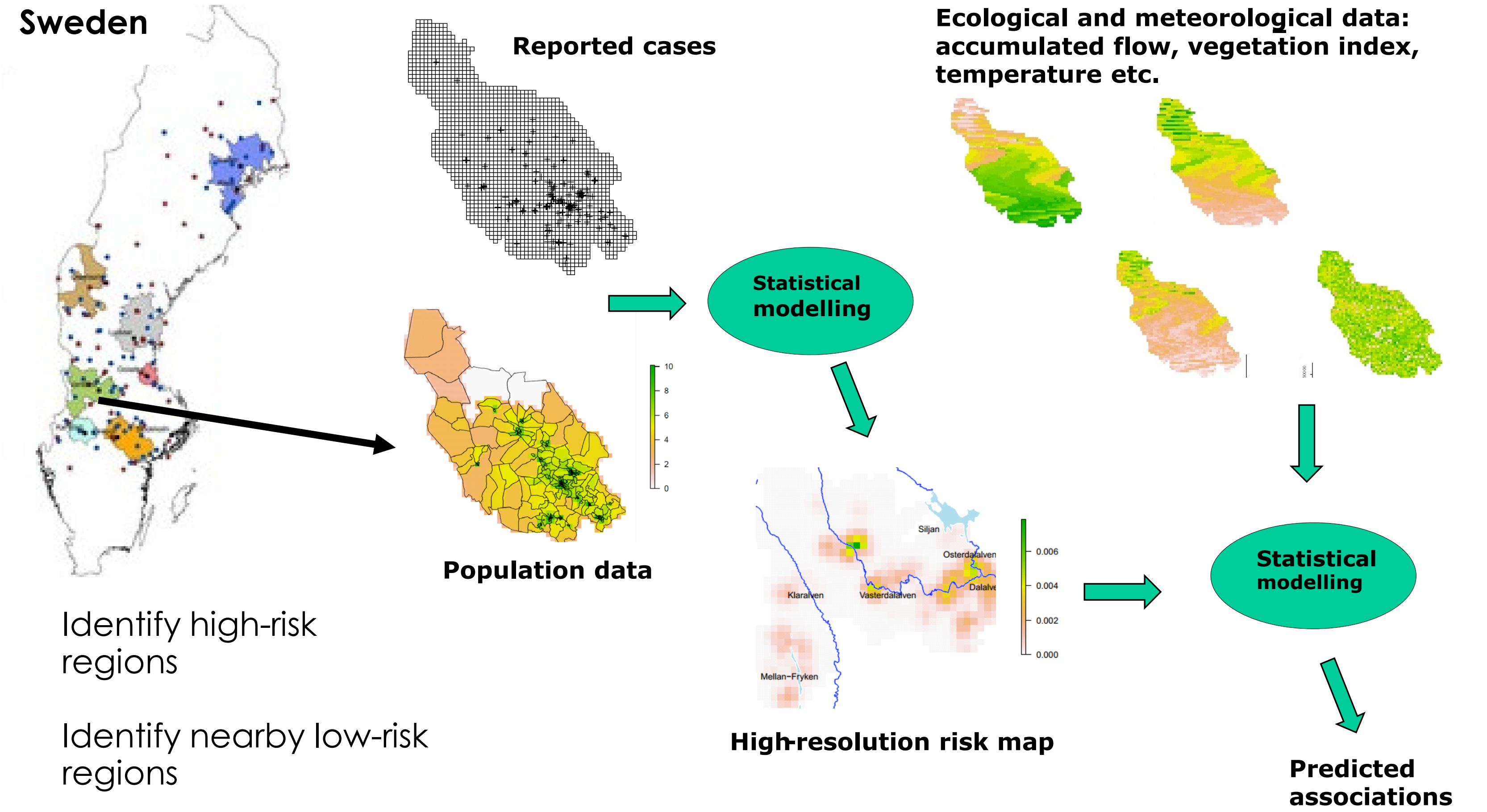
Figure: Spatial spread of dominant plant functional types (pft) in each grid cell for years 2020, 2050 and 2100 for the change scenario of +3,7° by 2100 (RCP8.5). Pft color-coding as in previous slide.

Chapter 5:
Environmental envelopes affecting the prevalence of CSI

Whether the geographical spread of an infectious disease truly depends on climate change or not, will depend on many factors.

We need to understand how variables such as climate, landscape, vegetation and the biology of vector and reservoir organisms influence the ecological niche of the respective pathogen.

Ecological niches associated with tularemia



Identify high-risk regions

Identify nearby low-risk regions

Figure: Study outline to understand the ecological niches associated with the tularemia risk at a refined scale.

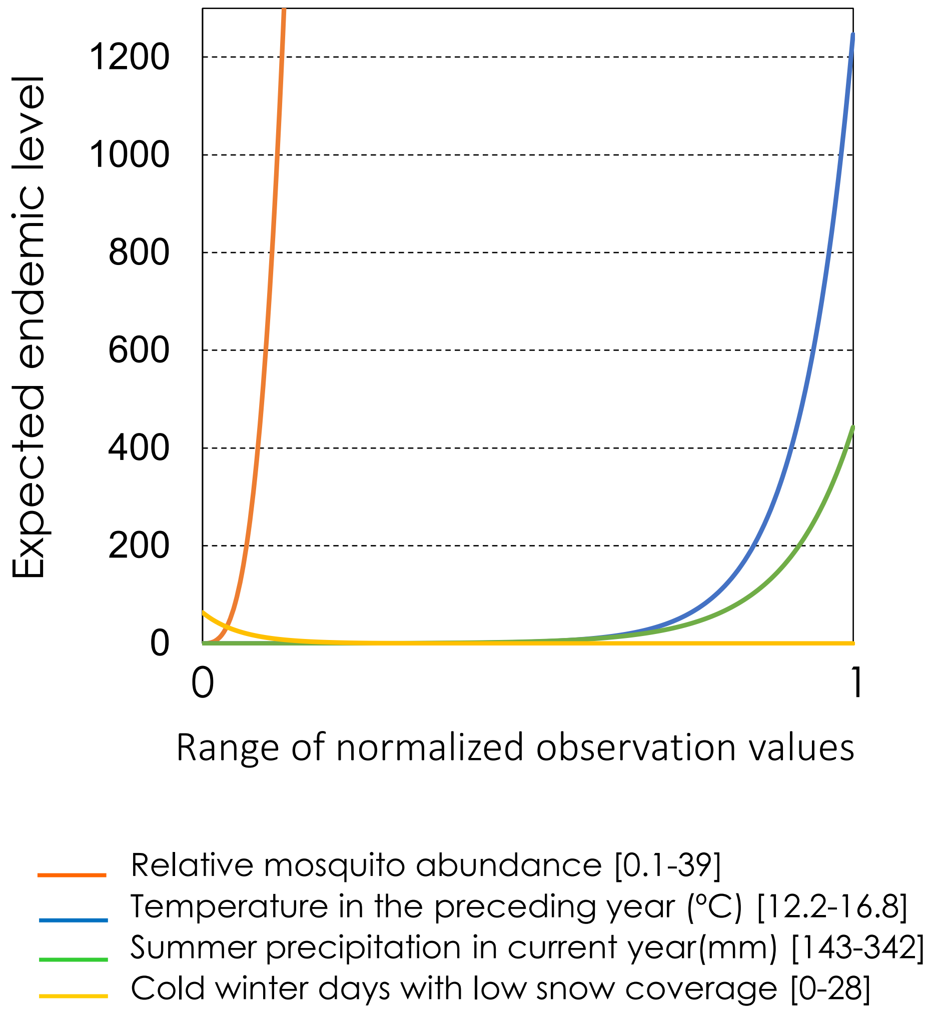
Why?

Predict how climate change will affect the identified niches and thereby tularemia abundance.

Process:

- Associations are made for all high-risk region – regional associations.
- Associations observed in several regions.
- Identify ecological niches associated with tularemia risk.
- Study the tularemia outbreak in "the Boden area" 2014-2019 (> 500 human cases).

Tularemia sensitivity to hydro-climatic change



Tularemia statistical model

Past observation of hydro-climatic variables

High sensitivity of tularemia outbreaks to certain combinations of hydro-climatic variable values

Figure: Endemic levels of tularemia in relation to hydro-climatic variable values (normalized to the same range [0-1]).

CLINF

NordForsk

Correlation between average annual air temperature and number of tick-bitten humans (1)

The northern border of *Ixodes* tick distribution goes through the North of European Russia. We want to understand, whether this border is affected by climate change.

Statistical data on tick-bitten humans have been collected in Arkhangelsk Oblast and the Republics of Karelia and Komi for several decades.

For the same regions we calculated the local average annual air temperature.

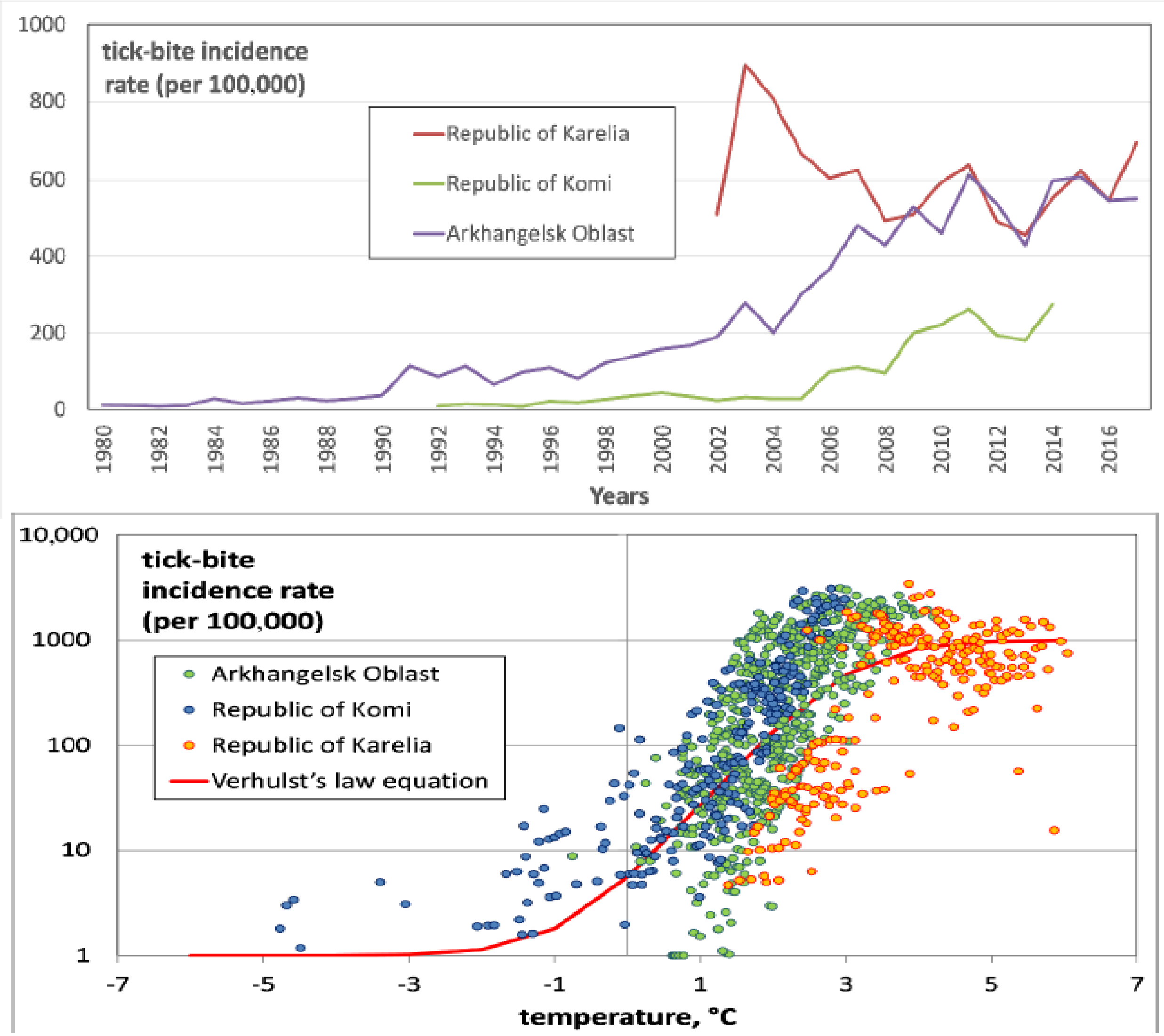
We found that the number of tick-bitten humans correlates with the average annual air temperature in an S-shaped distribution, which can be described as "Verhulst's law" or logistic function.

CLINF

Tronin et al. (2020) Intl. J. Env. Res. Public Health 17:8006; https://doi.org/10.3390/ijerph17218006

NordForsk

Correlation between average annual air temperature and number of tick-bitten humans (2)



Between +0,5 C to +4 C the tick-bite incidence rate increased exponentially.

An average air temperature above 4C did not result in higher tick-bite frequency.

A tick-bite incidence rate of a few thousand per 100 000 inhabitants may be considered as a saturation value.

From these results we conclude that above +4 C the size of the tick population appears to be rather stable.

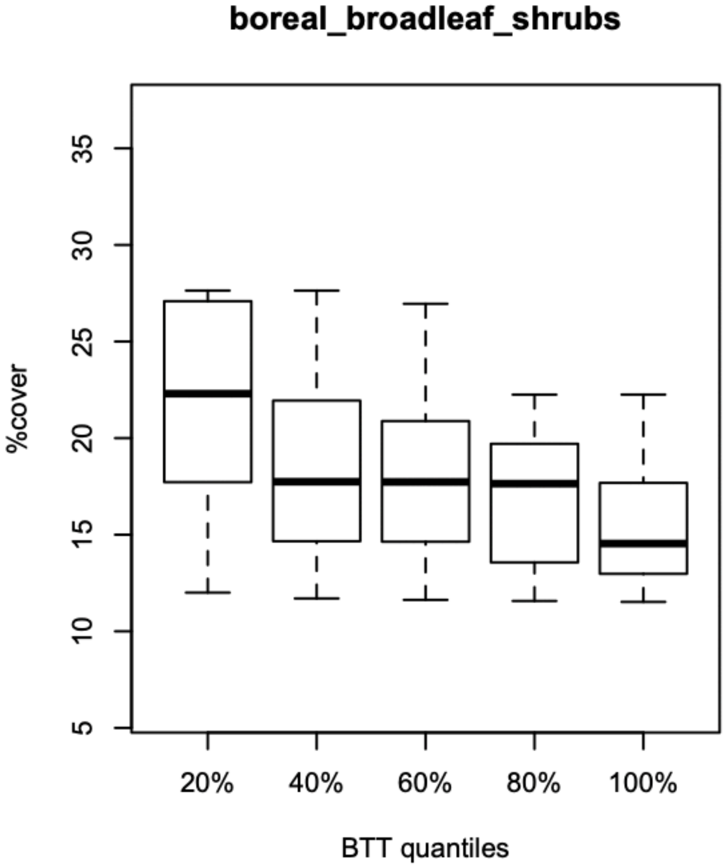
Figure: Tick-bite incidence rate per 100 000 inhabitants for 1980-2016 in three regions of the European North of Russia (top) and in relation to the average annual model air temperature for the respective region (bottom).

CLINF

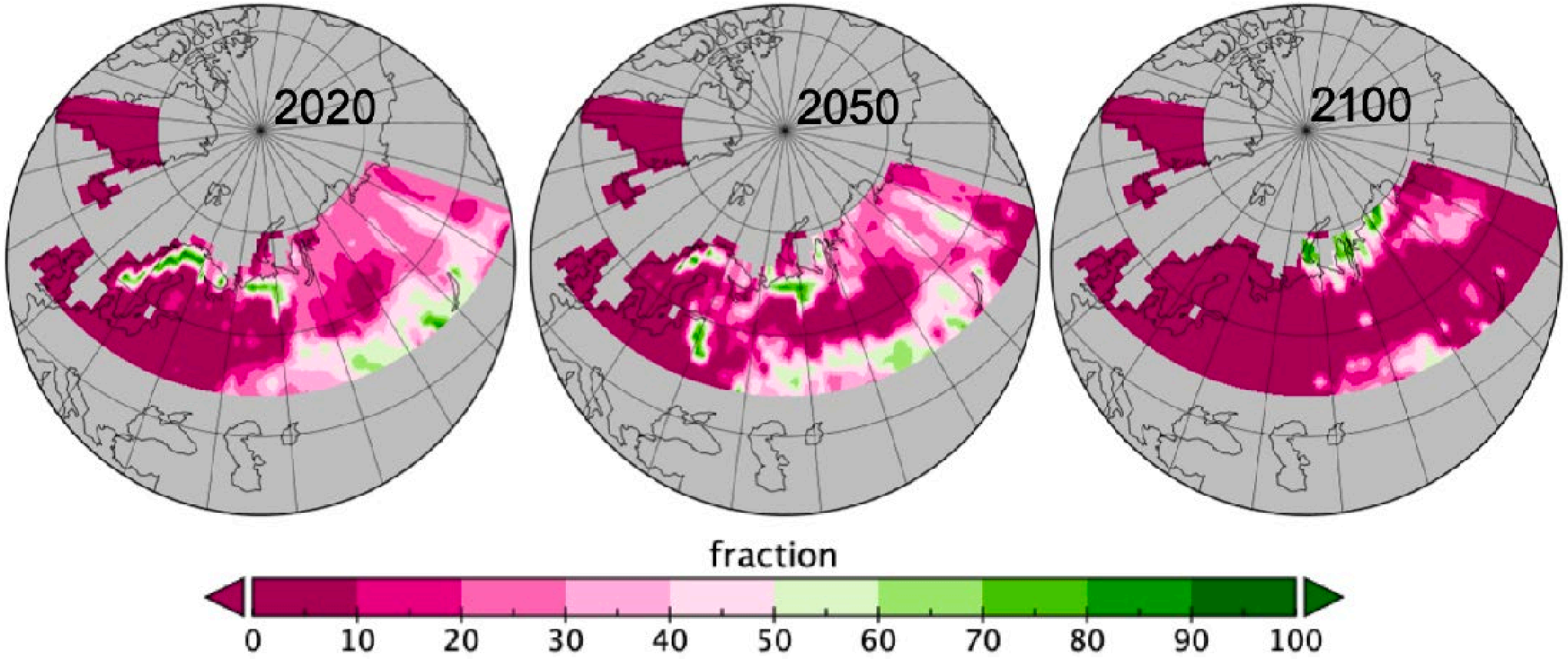
Tronin et al. (2020) Intl. J. Env. Res. Public Health 17:8006; https://doi.org/10.3390/ijerph17218006

NordForsk

Negative correlation between boreal broadleaf shrubs cover and selected CSI



Boreal broadleaf shrubs will decrease in Fennoscandia but increase in Arctic Russia.



Figures: Boxplot diagram showing cumulated incidences of borreliosis, tick-borne encephalitis and tularemia for the period 1985-2015 in the CLINF research area in relation to the percentage of land covered with boreal broadleaf shrubs (left), and percentage of land covered with boreal broadleaf shrubs modeled for the years 2020, 2050 and 2100.

Chapter 6:
Future CSI geographies

When we understand the relationship between environmental variables such as climate, landscape, vegetation or vector biology and the geographical spread of an infectious disease, we can forecast the future distribution area of this disease.

Example tularemia: Future scenarios of high-risk areas in Sweden

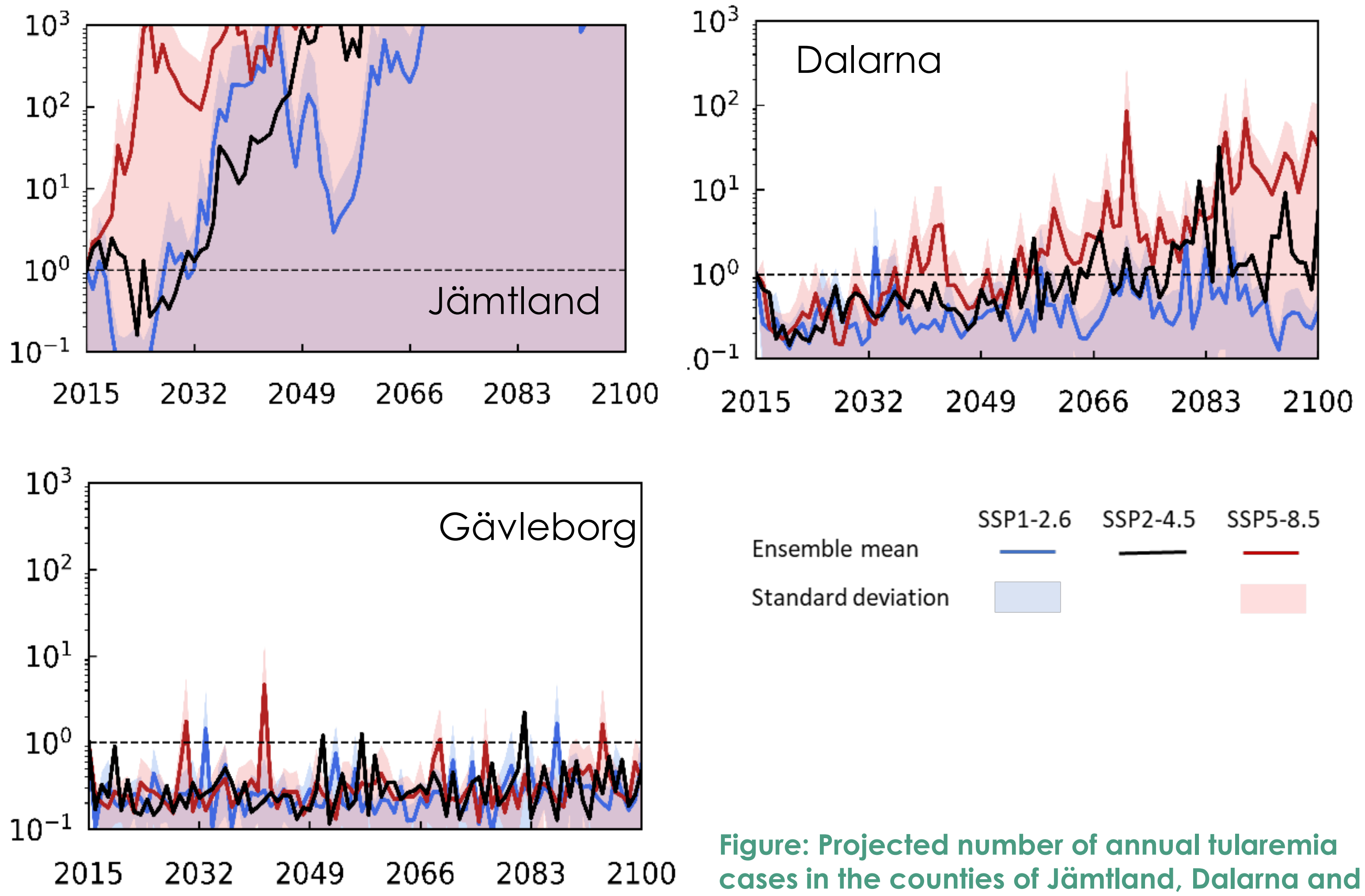


Figure: Projected number of annual tularemia cases in the counties of Jämtland, Dalarna and Gävleborg for 2015-2100 and three climate change scenarios, SSP1, SSP2 and SSP5.

Tularemia statistical model

Disease surveillance data

Global Climate Models (CMIP6)

- Highly divergent changes in future disease outbreaks among Swedish counties.
- Scenarios of steeper future climate warming do not necessarily lead to steeper increase in future disease outbreaks.
- Inter-model uncertainties can be large.

Chapter 7:
Impact of CSI on northern societies

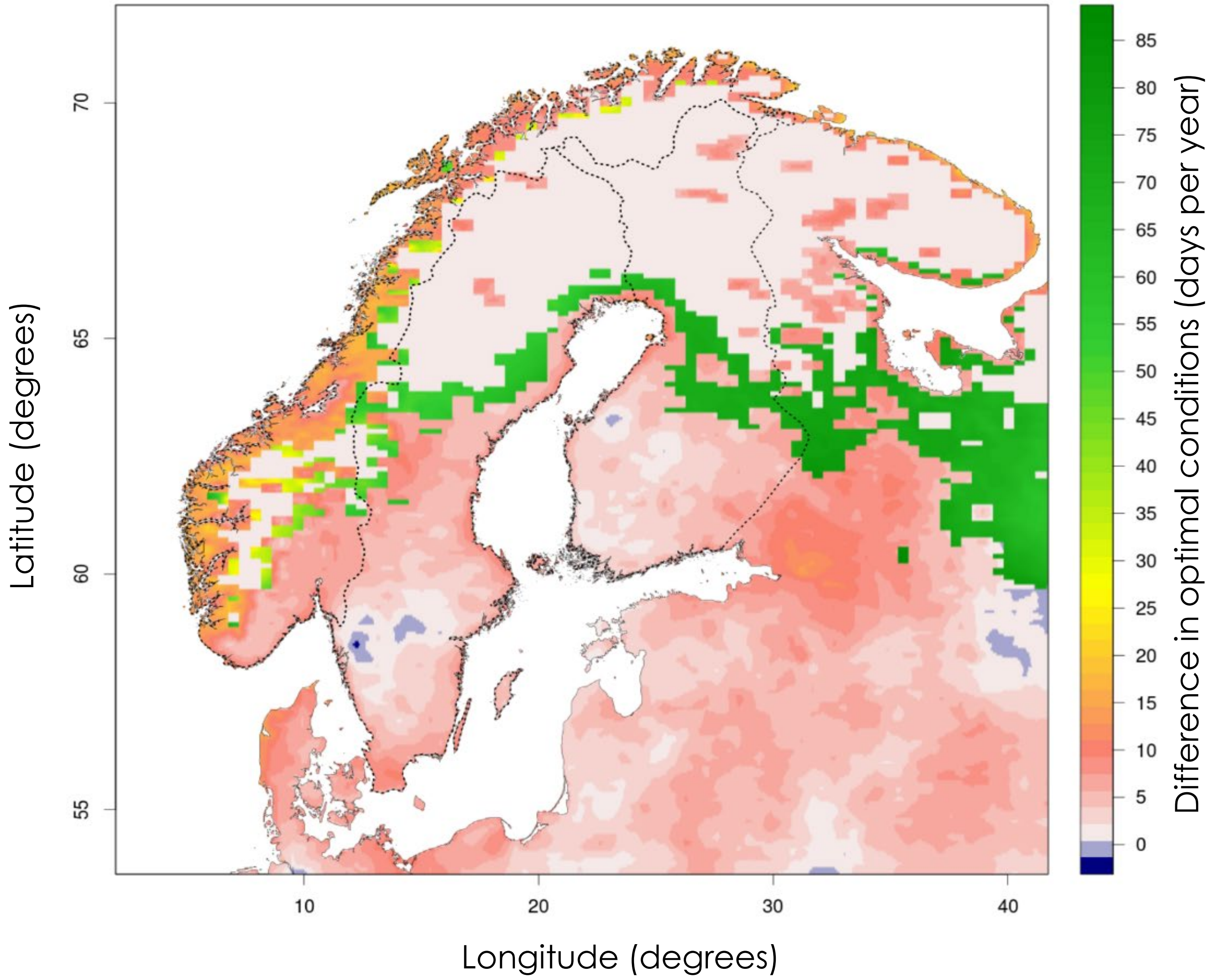
How might an increased risk of infectious diseases affect the people living in the North, their economy, their health and their culture?

The livelihood and the rights of reindeer herders and sheep farmers are threatened on many levels.

Which role may an increased pressure from CSI play for the ability of pastoralist communities to make a living?

How do CSI interact with other challenges of living in the North?

Tick-borne diseases and reindeer management (1)



Climatic projections until 2050 (RCP4,5) suggest that in the Nordic region

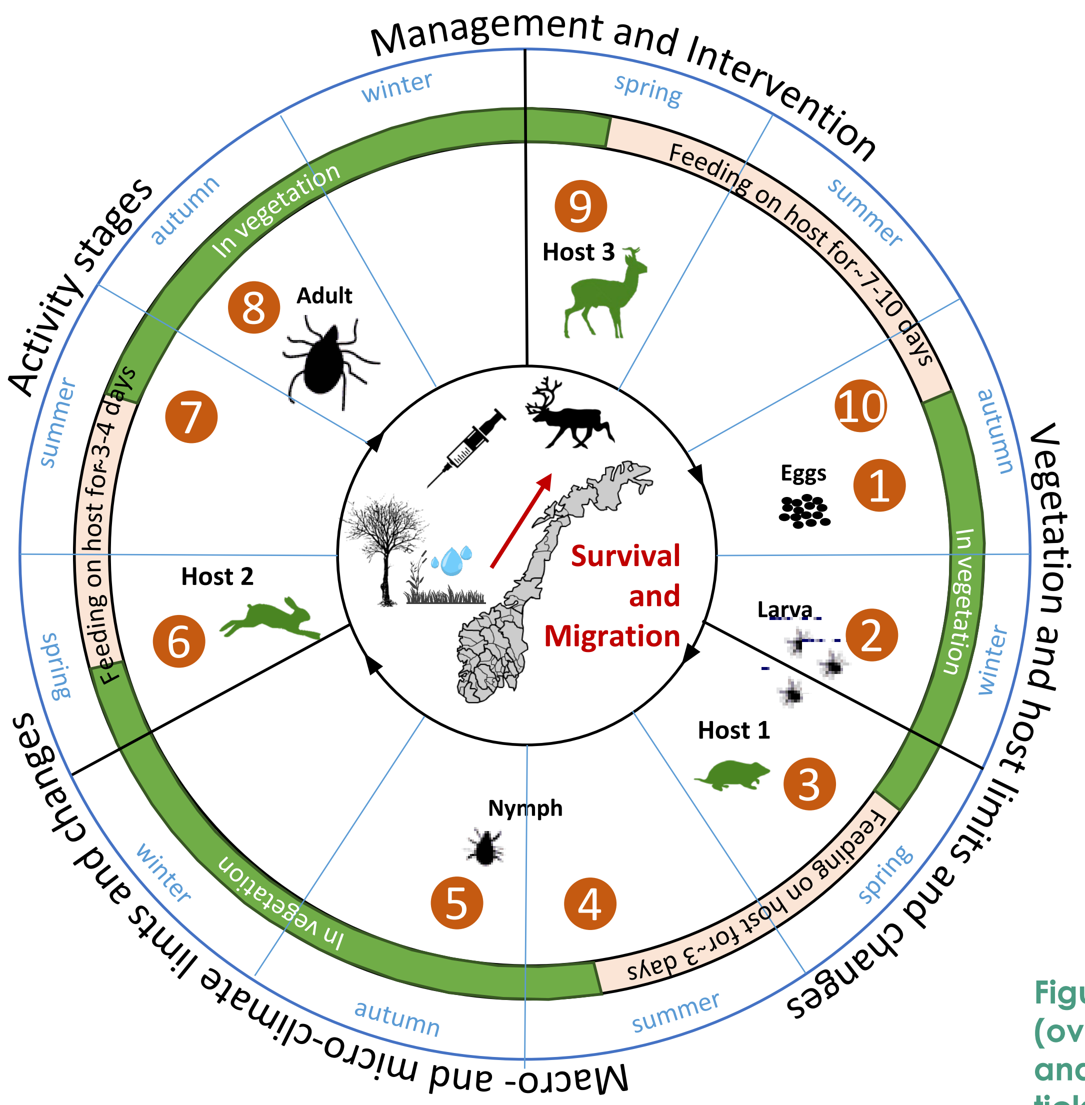
- the tick season will get longer and
- the geographical distribution range of *Ixodus* ticks will expand northwards.

Changes in optimal climate conditions for tick development will lead to increased tick activity and to an increased risk of disease transfer.

Figure: Difference in number of days per year of optimal climatic conditions for tick development, based on climate data from 1995-2015 and forecasted to 2030-2050 in the RCP4,5 scenario.

van Oort et al. (2020) Intl. J. Environ. Res. Public Health 17:5387; https://doi.org/10.3390/ijerph17155387

Tick-borne diseases and reindeer management (2)



Climate change plays an important role in increased risk of tick-borne diseases. However, management of vegetation changes, disease hosts and vectors plays a significant role in determining, whether these CSI spread in the population.

Appropriate and seasonal management emerges as an important regulatory "tool" for reducing the risk for tick-borne diseases. Especially, shrub encroachment and pasture- and animal management are important factors.

Figure: The *Ixodes ricinus* (tick) life cycle and linkages with its environment. Development, inactive (overwintering) and active (questing and on host) stages, climate limits and changes, preferred hosts and vegetation, management and interventions all form boundaries for the survival and migration of ticks and the CSI pathogens they carry.

CLINF

van Oort et al. (2020) Intl. J. Environ. Res. Public Health 17:5387; https://doi.org/10.3390/ijerph17155387

NordForsk

Photo: C. Risvoll

CSI as one of multiple stressors – Risk and uncertainty in pastoralism in northern Norway (1)

Pastoralism is challenged by many interacting drivers of change. These include pressure from large carnivores, encroachment and changing climatic and environmental conditions such as locked winter pastures due to frequent freeze-thaw events.

For pastoralist communities the return of investment has been gradually decreasing for some time, a trend that has accelerated in recent years. Despite high internal robustness, pastoralism is at a cross-roads, economically and culturally, leaving pastoralists with limited prospects for sustainable adaptation.

CSI as one of multiple stressors – Risk and uncertainty in pastoralism in northern Norway (2)

Rationalizing responses supported by the authorities are often highly technical, such as stringent wildlife-pastoral interactions or supplementary feeding, and fail to holistically manage ecosystems.

Supplementary feeding is a technical solution to combat the problem of lost access to pastures or of animal losses due to predation. But this adaptive response has multiple consequences; one being an increased risk of infectious diseases spreading in the herd.

This risk should be seen in combination with other stressors and changes that often exacerbate each other.

Risvoll et al., manuscript in preparation Feb. 2021: *Falling between the cracks of the governing system: Risk and uncertainty in pastoralism in northern Norway.*

Chapter 8:
Adaptation strategies for pastoralists in the North

Frequent freeze-thaw events lead to icy layers that make it difficult for reindeer to reach the ground vegetation and to graze.

Roads, railways, extractive industries, hydroelectric power, windmills and recreational activities cause land fragmentation and reduce the access to grazing land for reindeer.

How do adaptation strategies to such stressors interact with the risk of CSI?

Adaptation to multiple stressors and cumulative effects (1)

Herders adapt to locked pastures for example by moving their reindeer to lower altitudes (in Sweden) or to coastal lowlands (in northern Norway).

Supplementary feeding is an adaptation strategy used in cases of pasture encroachment and pressure from large carnivores. However, this alters animal behavior and land-use and increases the likelihood of infections.

To avoid disease transmission, the animals should not be kept too close together and a variety of pastures should be used.

Adaptation to multiple stressors and cumulative effects (2)

Climate change affects the spreading of CSI to new geographical areas and increases the transmission risk to reindeer. Ticks are moving northwards along the coasts. At the same time grazing sheep reduce the shrubbery and thus, the spreading of ticks.

A traditional adaptation strategy that is still in use is to move the animals to higher ground to alleviate insect infestations. This may prove useful against ticks as well.

Pastoralists easily adapt to individual stressors. But when looked at in combination, these multiple stressors become a complex challenge. Currently, CSI are a wild card in this web of interactions. However, when the flexibility in using a variety of pastures is further reduced, CSI may become a more prominent stressor in this web.

Hovelsrud et al. (2020) in Nordic Perspectives on the Responsible Development of the Arctic: Pathways to Action. Ed. D. Nord. Springer

Adaptation to multiple stressors and cumulative effects (3)

Keeping sheep or reindeer in confined spaces puts the animals under stress and increases their susceptibility to infection. There is a strong connection between outfield grazing and animal health and welfare.

To safeguard animal health and to keep future risks of expanding CSI low, it is critical to protect pastures from encroachment and to prevent further fragmentation of grazing land.

Traditional knowledge has been an important element of adaptation. Today, CSI are no major problem for pastoralists in the North. But CSI pose a risk that pastoralists may have to address in the very near future.

A holistic approach to understanding adaptation is necessary, but not straightforward. Yet, without such an approach, we might miss many critical linkages and causalities.

Photo: C. Risvoll

Co-production of knowledge: The issue of supplementary feeding (1)

In March 2018 the three Nordic Centres of Excellence CLINF, ReiGN and REXSAC organized a workshop with scientists and reindeer herders from Norway, Sweden and Finland.

Highlights regarding supplementary feeding:

- It is not considered a long-term solution to the problem of inaccessible pastures.
- It is avoided as long as possible. But the need to start feeding before starvation and emaciation in order to allow the reindeer to adjust to the feed is recognized.
- It requires specific knowledge and skills. Knowledge exchange between herders is helpful, even necessary.

Horstkotte et al. (2020) *Supplementary feeding in reindeer husbandry – Results from a workshop with reindeer herders and researchers from Norway, Sweden and Finland.* Umeå University

Co-production of knowledge: The issue of supplementary feeding (2)

Highlights regarding supplementary feeding:

- Increased necessity for supplementary feeding may threaten reindeer husbandry traditions and culture as well as the transfer of experience-based knowledge from one generation to the next.
- Thriving reindeer is the most important aspiration for reindeer herders. Advantages of supplementary feeding include increased reindeer survival and better control of the herd. Drawbacks are the costs for the feed and the extra workload, among others.