Research Report **Tick Talkers**

Lyme borreliosis is the most common tick-borne disease in Germany. As ticks are influenced by climatic factors, we used data on temperature and precipitation from 2016 to 2022 in Bavaria to develop a model predicting the future incidence of Lyme borreliosis. Despite some limitations, our model helps to better understand future trends of Lyme disease incidence and provides actionable information for the public to develop prevention strategies and raise awareness for tick bite prevention and treatment.

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Preface by the Supervisor

Prof. Niklas Fanelsa

Staying together in a natural setting, away from daily routines and the city, while sharing knowledge and working together, is a good approach. Walking in nature, taking a swim, and sharing local food make up a holistic experience. Workshops and sessions led by renowned scientists and experts create an immersive learning environment. These strategies influenced the foundation of the historic Black Mountain College (1933–1957) and resonate with the principles of TUMJA.

Well-designed spaces play a crucial role in fostering creativity and knowledge creation. I have had the opportunity to experience various seminar spaces around Munich selected by TUMJA for their gatherings. It is only logical that TUMJA envisions its own seminar house to reflect its values and ideas. As a member of TUMJA, I therefore support the establishment of a new seminar house. At Starnberger See, TUM has the unique opportunity of transforming the historic Hans-Albers-Villa, to create a space for international exchange and mutual learning.

As a first involvement, I had the chance to co-organize a student workshop in April 2024, focusing on the new cladding of the reed roof. Together with professional craftsmen, seventeen students had the opportunity to get their "hands on reed" at the existing boat house. They will probably still remember which pieces they added once they return to the finished seminar campus as alumni.

Supervisor insights

What special experience from your studies/career would you like to share with the scholars?

We have to address the current Polycrisis by understanding its wicked problems in order to design intelligent solutions. Teams with multi-perspective views from diverse backgrounds have the best chances of succeeding in this challenging task. The teams of TUMJA lay the foundations for the future team engagement of its members.

What does mentoring the team mean for your own research?

For me, mentoring means sharing knowledge at eye level while being open and curious. Coming from a design background, I value TUMJA for exposing me to professionals and students from natural sciences and social sciences with methods and knowledge production that are uncommon to my field of research. Through this, I get a better understanding of how collaborations that draw on different backgrounds can complement each other.

Supervisor insights

Prof. Dr. Enkelejda Kasneci

As the supervisor of Tick Talkers, I am delighted to see the team's development through the TUMJA program in conducting research, working collaboratively, and managing tasks. Their journey began with brainstorming and identifying a relevant research question. Drawing on their diverse expertise, they chose to focus on the impactful topic of climate change and Lyme disease infection. Through the project's execution, they gained valuable experience in cutting-edge technologies such as Artificial Intelligence and Machine Learning. At the science fair, they successfully introduced and advertised their work, earning recognition from all attendees. I am confident this synergy will continue to drive each team member's development and inspire further achievements.

What was your best TUMJA moment?

I was proud and impressed when the team reached out to a biomedical professional and successfully obtained an expert opinion. This step showed their confidence and motivation for the project, turning their enthusiasm into meaningful and proper action. Such a move is challenging yet essential in every researcher's development, and at that moment, I felt the TUMJA mentoring program had paid off. ■

By year 2050 the incidence of Lyme disease in Bavaria, Germany will have risen to more than 1000 per year

An interdisciplinary group of students named Tick Talkers recently established a predictive model linking climate factors to the number of ticks and Lyme disease in Bavaria. The project was developed under the framework of the TUMJA and aims to predict future numbers of ticks and Lyme disease cases in different regions of Bavaria.

As there is an established link between climate factors and ticks, not only scientists and health professionals but also the general public will direct attention towards changes in the spread of tick-borne diseases. From hikers navigating Bavaria´s countryside, residents in endemic regions, to healthcare systems, the implications of this complex relationship requires the need for proactive measures and increased awareness.

For the creation of this model, historical data of reported cases of the disease and climatic factors, such as temperature and precipitation were utilized. The data was gathered in Bavaria from 2016 to 2022. The model showed that the incidence of the disease is closely linked to climatic factors. The interplay of milder winters and variability in precipitation have created an environment conducive to the proliferation of ticks carrying Borrelia, the pathogen causing Lyme disease. The research also draws parallels with similar events in other parts of Europe and the USA.

Lyme disease is an infection caused by a bacterium (*Borrelia burgdorferi*) which is hosted by ticks. The bacterium, and thus the infection, is transmitted to humans using the tick as a vehicle. Typical symptoms appear as skin rashes, joint and muscle pain, headaches, and fatigue. Early detection of the bite and antibiotic treatment by medical doctors can treat the disease. However, if left untreated, the pathogen can spread to the nervous system, joints, and heart, followed by long-term health issues.

To make those predictions accessible to the general public, the Tick Talker group created an interactive website, with information about estimated numbers of ticks in different regions of Bavaria. Thereby, zones at high risk of infection are highlighted to caution the public. Additionally, the website informs users of general information about ticks and the disease and protection against tick bites. Also, tips on what to do in case of a tick bite and further information can be found.

Despite protecting individual health using preventative measures such as vaccination and tick checks, early detection of a potential increase in high-risk areas becomes a broader concern. The situation underscores a broader societal implication requiring a collective response to effectively allocate resources and mitigate the escalating threat.

Tick Talkers

Research Report – Tick Talkers

Abstract

Lyme borreliosis, an infectious disease transmitted by ticks, is the most common tick-borne disease in Germany. After infection has happened, the disease is divided into three clinical stages. In the early stage, the infection can be treated with antibiotics, while late manifestations can severely affect a person's health and quality of life. Therefore, the early detection of a tick bite and prediction of future incidence rates can improve resource allocation and communication with the public. As ticks are influenced by climatic factors, we used data on temperature, precipitation, and sunshine duration from 2016 to 2022 in Bavaria to develop a model predicting the future incidence of Lyme borreliosis. We fitted an autoregressive moving average (ARIMA), a statistical analysis model used to forecast future trends. Thereby, the variable of interest is influenced by both current and past values of the independent variables. In addition to strong correlations between the input variables and the outcome measure, a temperature rise of 2.8 °C is expected to result in a 5%-10% increase over current levels. However, the complex disease dynamics and the lack of land use data may affect the accuracy of our predictions. Despite these limitations, our model helps to better understand future trends of Lyme borreliosis incidence and provides actionable information for the public to develop prevention strategies and raise awareness of tick bite prevention and treatment.

Background

Lyme Borreliosis (LB) is the most common tick-borne disease in Germany (Böhmer, et al., 2021). In 2023, Skufca et al. reported an annual incidence of 37.2 per 100,000 person-years on average from 2016 to 2020 (Skufca et al., 2023). Böhmer et al. showed comparable results with an annual incidence of 34.3 cases per 100,000 inhabitants in Germany from 2013 to 2020 (Böhmer et al., 2021). The lowest rates were found in 2015 with 23.2 cases per 100.000 and the highest were found in 2020 with 47.4 cases per 100.000 person-years. Nevertheless, an approximately ten-fold higher number of unreported cases is estimated.

Even though Germany is a high-risk country for LB, it is not a notifiable disease in 7 out of the 16 federal states. That explains that the actual number of LB cases is estimated to be higher than those that were reported. When analyzing the annual incidence, it is noticeable that 68% of all LB cases were reported between June and September. There is a high variation in the risk of Lyme disease depending on region, season, temperature, and a variety of other factors.

After infection by *Borrelia burgdorferi* has happened, the disease can be divided into three clinical stages. The first stage is on the skin, lymphatic, and nervous system. Following the early dissemination phase, the heart and musculoskeletal system can also be affected. Occasionally eyes are affected as well (Girschick, H. J., et al., 2009). Finally, chronic neuroborreliosis can develop, which might disrupt cognitive functions, change behavior, and impact gait stability and bladder function (Koedel et al., 2015).

As late manifestations of the disease have a severe impact on an individual´s health and quality of life, it´s important to prevent and detect tick bites early. Therefore, awareness of the following symptoms indicating an infection should be raised.

Nowadays, infected patients are treated with intravenous injections of penicillin, ceftriaxone, and cefotaxime or oral intake of doxycycline. (Girschick, H. J., et al., 2009). A vaccine for Lyme Disease developed by Pfizer and Valneva is currently being tested in clinical studies, according to the latest press release, with the expected trial conclusion date by the end of the year 2025 (Valneva & Pfizer, 2023). However, as further evaluation is needed, the vaccine is not available for the public. Therefore, knowledge about the pathology of this disease and the importance of its prevention is still crucial.

In Europe, *Ixodes ricinus* is one of the most abundant and widespread ticks and transmits LB and tick-borne encephalitis (TBE). The complete life cycle of a tick takes around 2 years to complete. It starts in spring when an adult female tick lays a batch of eggs. During summer, the larvae (6 legs) emerge and typically feed on small animals, like mice. This interaction between the host and the different life stages of the vector can be seen in Figure 1.

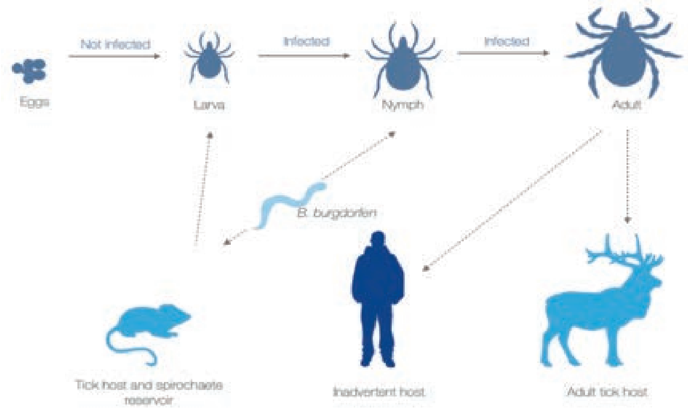

Figure 1: Vector and host relationship.

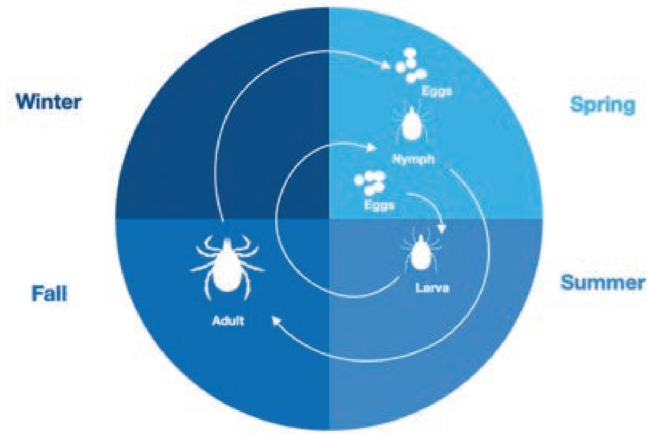

Figure 2: Tick life cycle through a year.

The mice are reservoirs for the bacteria that cause diseases, such as LB. The tick larvae can obtain the bacteria from them. During late summer, these larvae continue to grow into nymphs (8 legs). During winter, these nymphs stay alive under leaf debris.

In the second year, during spring, the nymphs emerge and feed on medium-sized animals. During this stage, nymphs are considered to be at the most dangerous life stage, regarding their infection risk. This is because they have a small size, therefore are hard to spot, and there is a high possibility of being infected with bacteria.

During the late summer, the nymphs grow into full adults. Once they reach a bigger size, the ticks feed on larger animals, such as deer. During fall and winter, the adult ticks can remain active, if the temperatures are above freezing point. The life cycle of the ticks based on the seasons of the year is shown in Figure 2.

The number of ticks, especially those infected with LB, is of major relevance. A study on Lyme Borreliosis in Germany from 2010 to 2019 showed that 5-22% of all ticks were infected with Borrelia. Whereas there were lower numbers in the north of Germany with approximately 5% of infected ticks in Mecklenburg-Vorpommern, in Bavaria, and in Baden-Württemberg, 12,8% and 22% of all ticks were found to be LB carriers (Akmatov et al., 2021).

The World Health Organization defines health as complete physical, mental, and social well-being, emphasizing the interconnectedness of personal health with biological, environmental, social, and health system factors.

Climate change affects health directly and indirectly, with the well-being and health of humans, revealing an intricate relationship with the environment. Key associations include the impact of temperature and humidity on infectious diseases, mortality, respiratory, cardiovascular, and neurological outcomes (Rocque et al., 2021).

In the case of vector-borne infectious diseases, meteorological factors such as temperature, precipitation, humidity, and wind influence their incidence. Extreme weather events contribute to vector-borne disease risks, influencing broader consequences such as political instability, and health system capacity, among others (Rocque et al., 2021).

Ixodes ricinus, the predominant tick in Europe, along with *I. persulcatus*, transmits LB and consequently TBE. Climate change can influence tick behavior, with warmer winters increasing winter activity and hotter summers altering seasonal patterns. Ticks, sensitive to environmental conditions, are affected by changes in distribution and abundance due to climate variations (Gray et al., 2007).

Winter activity of ticks increases the risk of infectious tick bites for forest visitors. Climate suitability modeling, considering microclimatic variables, highlights the importance of ecological niches in tick distribution. Changes in tick abundance may be linked to long-term climate cycles rather than permanent shifts (Gray et al., 2007).

Predicted climate changes may impact vegetation structure, affecting tick habitats. While the link between LB incidence and climate change is uncertain, mild winters may extend tick activity seasons, potentially leading to increased disease prevalence (Gray et al., 2007; Vermont Department of Health, 2018).

Ixodes ricinus exhibits flexibility in seasonal activity, adapting to diverse conditions across its geographic range (Gray et al., 2007). The impacts of climate change on tick-related diseases are multifaceted, influenced by local conditions, socioeconomic factors and ecological dynamics.

Similar cases have been reported throughout Europe. In Stockholm a combination of climate variables affecting ticks showed a significant correlation with the incidence of TBE cases between 1960 and 1998 (Lindgren, 2001). Samplings made between 2001 and 2002 in the Czech Republic reflected changes in altitude distribution, where an incidence of ticks carrying TBE increased at higher altitudes relative to the field studies made in 1957 and 1979-1980 (Daniel et al., 2004; Danielová et al., 2006).

Climatic factors play a major role in the vector's life cycle. However, this correlation is not straightforward. Transmission of tick-borne infections involves complex interactions among reservoirs, vectors, and humans, with climate change affecting each stage differently. Despite evidence of climate-induced changes in tick survival and activity, the precise factors influencing disease incidence remain challenging to determine due to a multitude of interconnected processes.

Health framing in climate communication remains under-utilized, and there is a call for increased explicit linking of human health and climate change to engage wider audiences. Health professionals and policymakers play a crucial role in climate communication, adaptation and mitigation, as adverse health outcomes will strain health systems and their workforces (Rocque et al., 2021). Recognizing the diversity of health impacts and addressing research gaps will aid in preparing for the escalating health challenges posed by climate change.

Predictive modeling plays a role in forecasting the incidence of infectious diseases in the future by learning from the past. It is already being applied, for example, in the early detection of epidemics, and has proven its worth with diseases like Malaria, Influenza, and Covid-19 (Kuhn et al., 2005).

An early prediction of infectious disease incidence can be used for the design of emergency response management systems, that enhance the mitigation, resource allocation, preparation, and responsiveness of an outbreak (Mukhopadhyay et al., 2022, Brett et al., 2017). Additionally, through effective communication of prevention and awareness campaigns, an engagement with communities and actors can be created, leading to a quick response.

Goals and Methods

This project takes off where previous publications and related works on climate change and tick-borne diseases stopped. In order to analyze the effect of climate change on the incidence of Lyme borreliosis, it is of interest to be able to forecast future incidences.

The predictions are estimated based on historical data from the Deutscher Wetterdienst and the Robert Koch Institut from 2016 to 2022 in Bavaria, Germany. The covariates used in the model are temperature and precipitation. A first approach also included sunshine duration as an exogenous variable which was later omitted due to the strong correlation with temperature.

Two predictive models using statistical regression methods were deployed in Python, testing an ARIMA and a Seasonal Decomposition of Time Series (STL) with exogenous variables. The available data was split into training and test data, which resulted in both models using the data from 2016 to 2020 for training and the data from 2021 and 2023 for testing. After comparing these two models based on the accuracy and plausibility of the predicted results on the test data, the choice was made to use the ARIMA.

The ARIMA model is a statistical analysis model that utilizes time series data to predict future trends and is particularly common in economics, weather forecasting, and capacity planning. This means it allows the dependent variable to be influenced not only by current values of the independent variables but also by the past values of the independent variables and possibly by its past values. The ARIMA model can be divided into three main components. As an autoregressive model, the evolving variable of interest is regressed on its own lagged values. The integrated component refers to the replacement of the actual data values by the difference between their values and the previous values.

The moving average as a third component of the model incorporates the dependency between an observation and a residual error from a moving average model applied to lagged observations (Hayes, n.d.).

Mathematically, a time series $\{x_t; t = 0, +/-1, +/-2, \dots\}$ is ARMA (*p, q*) if it is stationary and

$$xt = \varphi_1 x_{t-1} + \dots + \varphi_p x_t\text{-}p + w_t + \theta_1 w_{t-1} + \dots + \theta_q w_{t-q} \qquad \text{Eq.1}$$

with $\varphi_p \neq 0$, $\theta_1 \neq 0$, and $\sigma^2_w > 0$ and $\{x_t; t = 0, +/-1, +/-2, \dots\}$ is a Gaussian white noise sequence. The parameters p and q are called the autoregressive and the moving average orders, respectively. A process x_t is said to be ARIMA (*p, d, q*) if is ARMA (*p, q*) (Shumway et. al., 2017).

$$\nabla^{d} x_{\Delta} = (1\text{-}B)^d x_t \qquad \text{Eq. 2}$$

We fitted an ARIMA (1,0,1) model. This means that the autoregressive order is 1, indicating that the current value of the time series is dependent on the previous value. With an integration order of 0 no differencing is applied to time series and a moving average order of 1 indicates that the error term of the model is dependent on the previous error term.

Outcome and Discussion

Overall, we can observe that there is a strong correlation between the input factors of our model, namely temperature, precipitation and sunshine duration, and the incidence of Lyme borreliosis.

Temperature significantly impacts disease incidence, as shown by a Pearson correlation coefficient of 0.82 (Figure 3, top left panel). Similarly, sunshine duration has a moderate correlation with incidence rates, indicated by a correlation coefficient of 0.63 (Figure 3, top center panel). In contrast, precipitation shows a slightly weaker correlation of 0.39 with incidence rates (Figure 3, top right panel). Additionally, the lower panels of Figure 3 demonstrate the interdependencies among climate factors: there is a strong correlation between sunshine duration and temperature (correlation

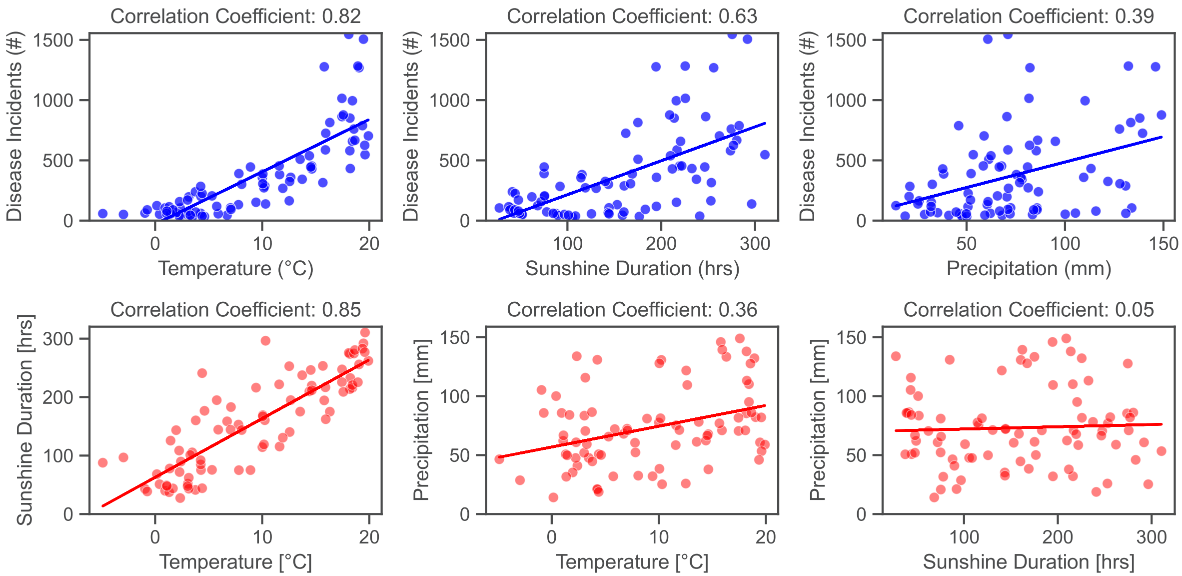

Figure 3: Correlation studies of different climate factors with disease incidence

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coefficient: 0.85, bottom left panel), suggesting that these factors do not vary independently. In contrast, precipitation is relatively independent from the other factors (correlation coefficients: 0.36 with temperature and 0.05 with sunshine duration, bottom center and right panels respectively). The near-zero correlation between precipitation and sunshine duration (Figure 3, bottom right panel) is illustrated with a linear fit, highlighting the lack of any significant positive or negative relationship. Based on these findings, in our model, precipitation and temperature are assigned higher weights to avoid redundancy and overemphasis on correlated variables like sunshine duration, ensuring a balanced and robust analysis.

For our predictions, we forecasted the incidence of Lyme borreliosis in four different greenhouse gas emission scenarios, also known as Shared Socioeconomic Pathways (SSCs), as released in the U.N. climate panel report released on August 9, 2021, according to which climate factors will change in different ways.

In SSP1-2.6 global CO_2 emissions are cut drastically, and net-zero will be reached after 2050 resulting in stabilized temperatures around 1.8 ºC higher by the end of the century. The second scenario, SSP-4.5, is a "middle of the road" scenario. While CO_2 emissions will start to fall in the middle of the century, net zero will only be achieved after 2100 and temperatures will rise by 2.6 ºC by the end of the century.

The SSP3-7.0 scenario assumes that CO_2 emissions will roughly double from current levels by 2100 with an average temperature rise of 3.6 ºC by the end of the century. The last and most dangerous scenario presumes a doubling of CO_2 emissions by 2050 and by 4.4 ºC higher average global temperatures by 2100 (Anthesis-Climate Neutral Group).

According to the Intergovernmental Panel on Climate Change, the current climate protection targets that governments around the world have set themselves could result in a warming of 2.8 ºC by 2100, which would be between scenarios two and three, namely SSP2-4.5 and SSP3-7.0.

Our predictions indicate that in the most lenient scenario, SSP1-2.6, the incidence of LB will hardly increase over the next decades with almost no incidence in the winter months and roughly 960 cases in the peak season in summer in all of Bavaria as shown in Figure 4. On the other hand, in the most severe scenario of an increase of global average temperatures by 4.4 ºC by the end of the century, the incidence will rise significantly by 2100. Even in winter months, which are nowadays characterized by very few to no infections, the incidence will have risen to 117 and to more than 1000 in the summer months. This is an increase of 4% compared to the most optimistic greenhouse gas emission scenario. As experts assume a temperature rise of 2.8 ºC, we can forecast an incidence between 1088 and 1151 during the peak tick season and 189 and 232 during the off-season, which indicates an increase between 5% and 22% to current levels. Figure 5 further illustrates the temporal change in lower/upper bounds of predicted incidence rates for different SSPs. These projections underscore the critical importance of considering various scenarios in planning and response strategies to mitigate potential health impacts.

However, the relationship between the tick population and the incidence of infection is complex, with many different variables interacting and influencing each other in parallel. Microclimatic variables such as soil surface temperature and relative humidity (which are affected by things such as slope and aspect, snow cover, vegetation, litter layer, humus, and underlying soils) can be critical in determining the distribution pattern of specific niches for tick survival within an area (Vermont Department of Health, 2018; Gray et al., 2008).

The influence of tick-borne diseases may be influenced by socioeconomic factors, human migration and settlement, ecosystems, and biodiversity, migrating patterns of birds, land-use and land cover changes, human cultural and behavioral patterns and immunity in the population.

Nevertheless, this study has shown the strong correlation between climatic factors and the incidence of infectious diseases. While Lyme borreliosis and ticks will most likely not be the topic with the highest priority when thinking of climate change and its effects, it still shows that these two topics are intertwined. Combatting climate change also helps in the dimension of health and the prevention of the spread of diseases.

Summary and Future Goals

This research project was initiated to explore the epidemiological impact of climate change on the incidence of Lyme borreliosis in

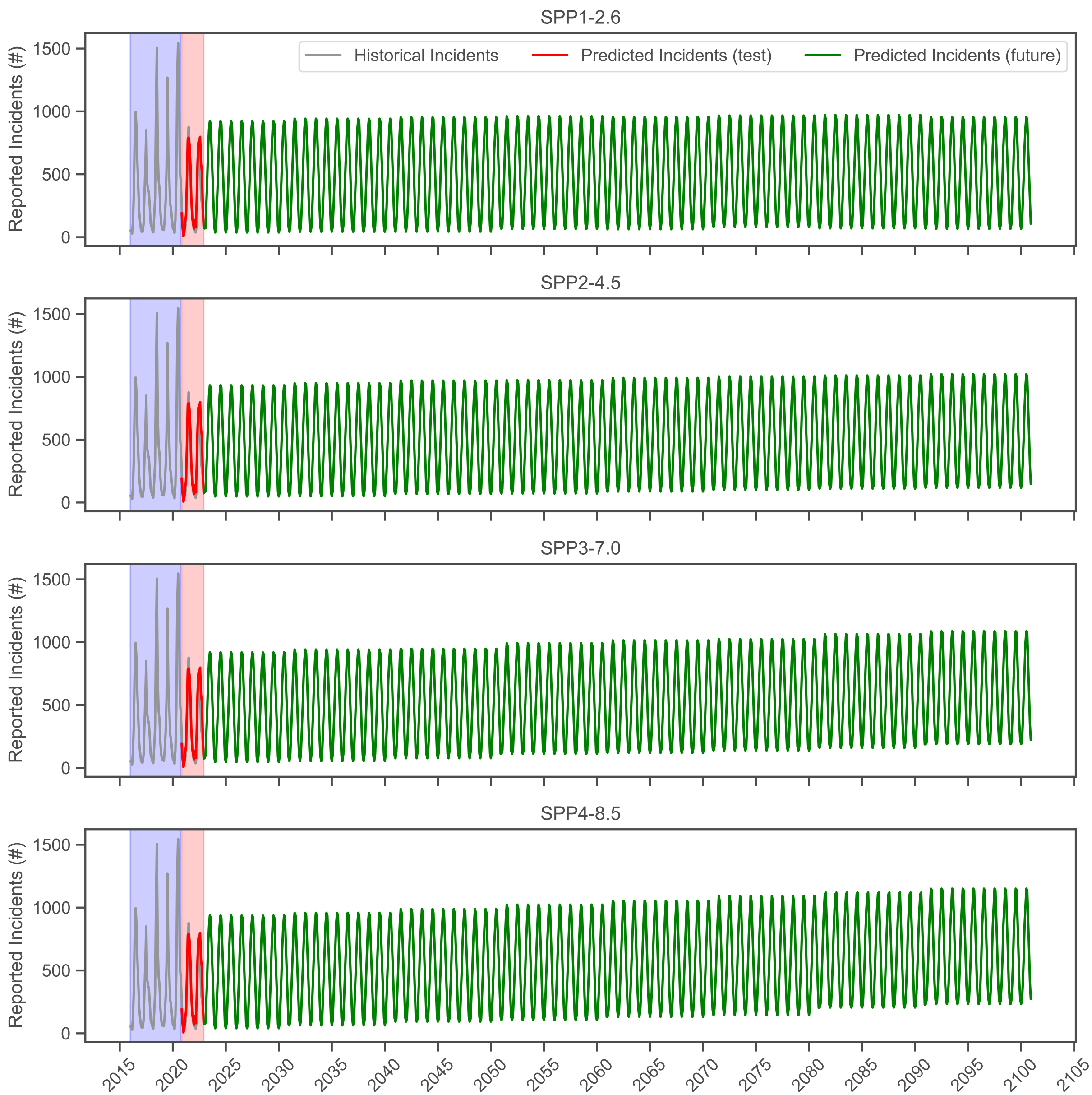

Figure 4: Predicted incidence rates for different SSPs.

Bavaria, aiming to bridge the gap in awareness and understanding of this emerging disease in Europe. Utilizing local data, we developed a predictive model to estimate the prevalence of LB from 2023 to 2100 under varying greenhouse gas emission scenarios.

Our findings indicate a direct correlation between the rise in greenhouse gas emissions and the incidence of Lyme borreliosis. In the most severe emission scenario, the incidence is projected to increase substantially, highlighting a critical window of risk and epidemiological severity. Conversely, in scenarios where global efforts successfully reduce emissions, the increase in LB cases is expected to be marginal. However, the complexity of the disease dynamics, influenced by factors such as host populations and human behavior, poses challenges to the predictive accuracy of our model. Data limitations, particularly the lack of detailed predictive land use data, further restricted the depth of our analysis.

To refine and expand our understanding, future research should focus on collecting more data from regions beyond Bavaria, conducting comparative studies with tick-borne encephalitis and other tick-borne diseases, integrating more detailed parameters to examine interaction effects more comprehensively, evaluating the potential impact of a Lyme borreliosis vaccine on disease incidence, and launching an awareness campaign informed by our findings, in collaboration with public health stakeholders.

These efforts will enhance our model's accuracy and deepen our understanding of disease dynamics. Additionally, they will help translate complex scientific findings into actionable information for the public, aiding in the development of effective preventive strategies. ■

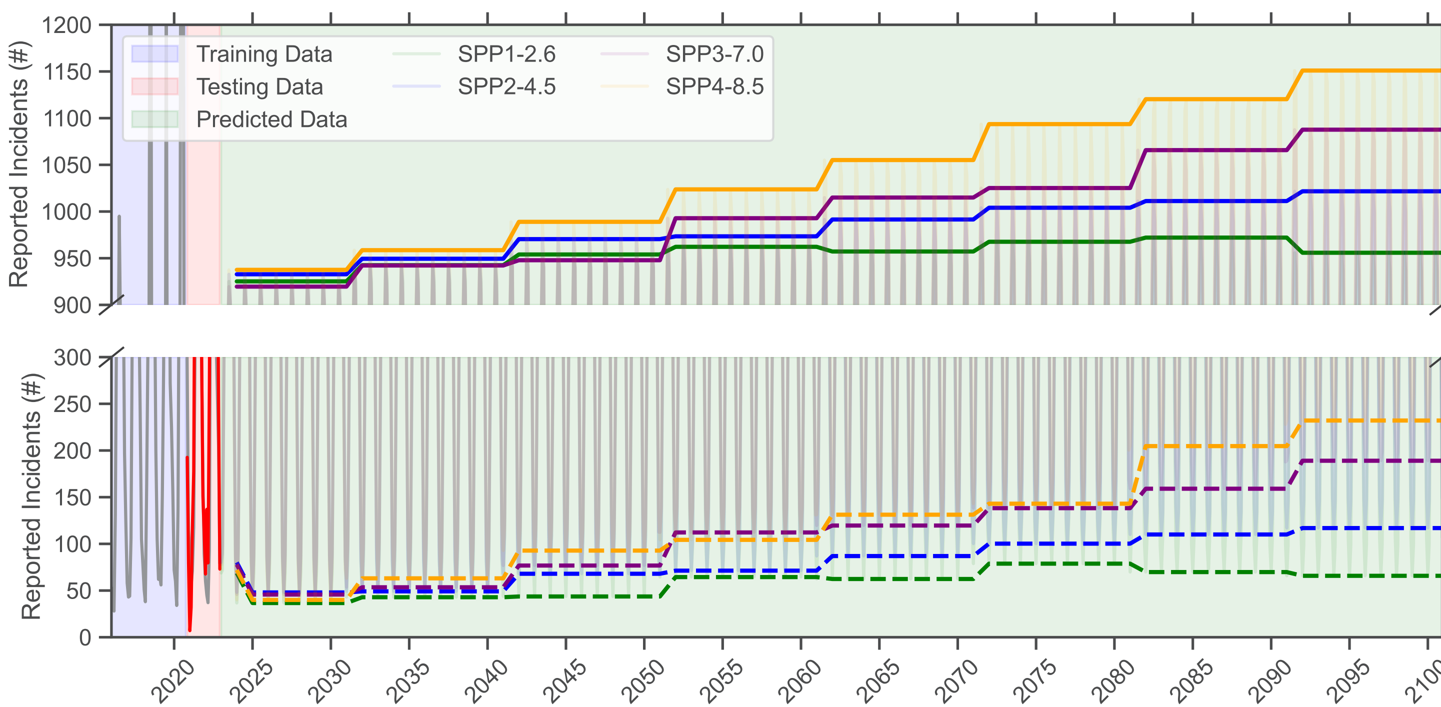

Figure 5: Temporal change in lower/upper bound of predicted incidence rates for different SSPs.

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Vermont Department of Health (2018). Climate Change, Lyme Disease, and Other Tickborne Diseases in Vermont.

Self-reflection

Our Team Tick Talkers is an interdisciplinary team of six students whose motivation united us in developing a project related to climate change and medicine. We started with the general idea of analyzing how climate change could affect our health. Our first thought was to focus on vector-borne diseases such as Dengue Fever or Malaria, as this first idea came up during a brainstorming session when we briefly mentioned that we didn't expect to have so many mosquitos, as it was late November, but it was relatively warm, so they were still around.

After a research phase considering data availability and weather relations of infectious diseases and other pathologies such as cardiovascular or respiratory diseases, we eventually decided to look at tick-borne diseases, as they are already prevalent in Germany.

After taking this decision on tick-borne disease, discussions moved on to the different use cases and the target audience for our project. As the call of our class is "Less is More: Empowering individuals to focus on the essentials," the first idea was to use our project as a tool to improve logistics and the distribution of medical resources to reduce medical waste and combat shortages of medical supply.

During the TUMJA seminars, we received feedback that helped us to narrow down the scope of our project and determine specific goals and milestones, which resulted in a more clearly defined project, namely to develop a predictive model for the incidence of Lyme Borreliosis in Bavaria up to 2100 based on temperature and precipitation.

The result was the objective to deliver a model that is accessible to the general public on a user-friendly website. The prototype of the website also provides general information about ticks, such as what they are, their life cycle, how to remove ticks, the disease itself, and general recommendations. As the idea of correlating weather data with disease incidence derived from a discussion within the context of climate change, the model includes predictions with different greenhouse gas emission scenarios. The goal is to evidence some of the not-so-obvious effects that climate change can have on different aspects of life.

After having decided on the predictive model as a more concrete project, we divided our team into a research team and a modeling team. While the research team focused on the theoretical backgrounds of the disease and the vector, as well as ticks' life cycles, the modeling team collected all the data and implemented the model.

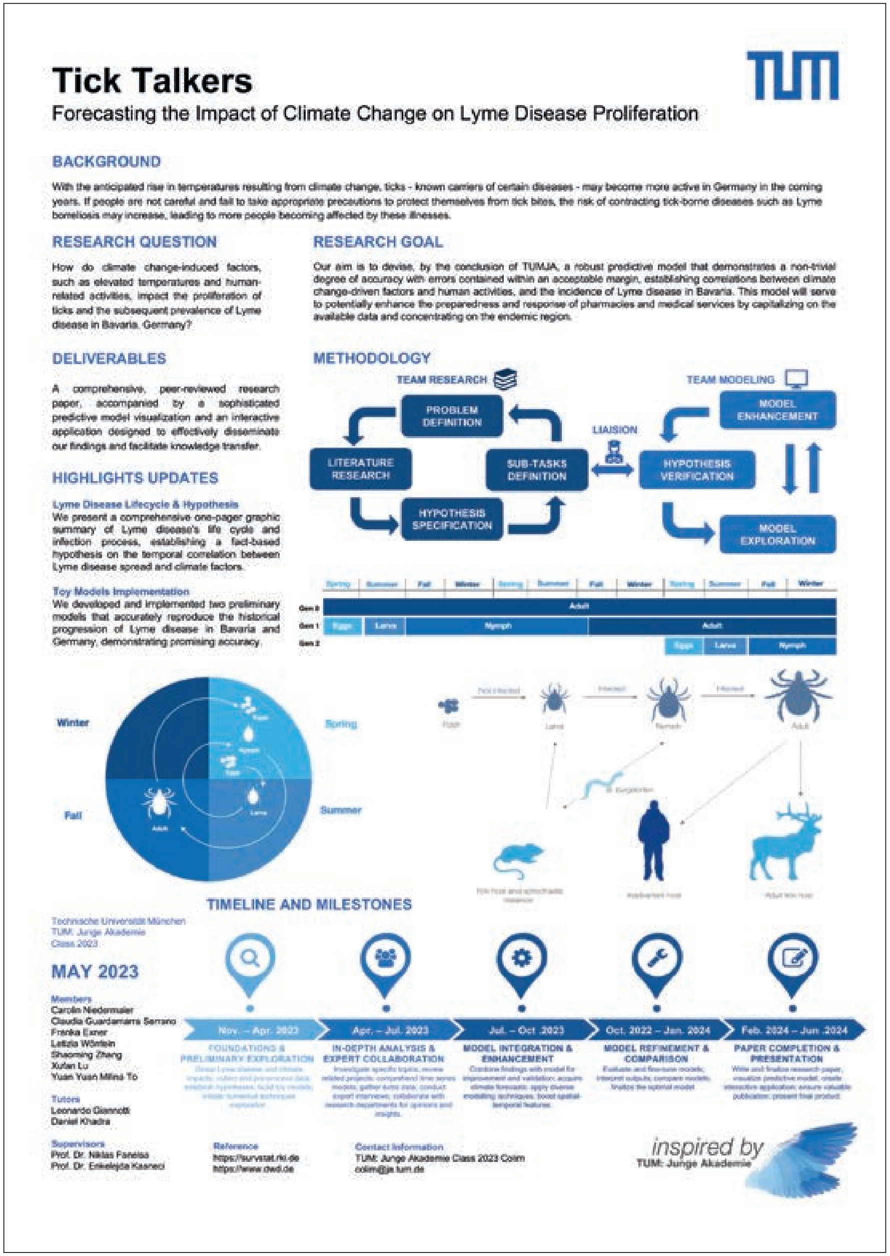
Overall, the Tick Talkers project was a valuable learning experience for all team members. However, one of our main challenges, mostly at the beginning of our project phase, was the coordination of the work, especially when team members were abroad or had other commitments, which sometimes led to a delay in our schedule. We all felt that a stronger push from the official TUMJA body to deliver not just posters but actual content a bit earlier throughout our time, along with shortening the sessions at the seminar weekends to leave more time for group work within the teams, would have helped us to implement further features into our project and advance more quickly.

We developed both hard and soft skills, ranging from academic and journalistic writing, coding, implementing a statistical model and data analysis, to teamwork, communication, and problem solving, which will be useful to all of us in our future endeavors. Furthermore, we learned how to overcome challenges and adapt to changing circumstances. Lively discussions, and scaling big ideas down to a project that is implementable in the setting of TUMJA, especially with all the other projects and deadlines everyone in our team had going on at the same time, are valuable key learnings.

In addition, we are deeply thankful for the professional support from our supervisors, Prof. Dr. Enkelejda Kasneci and Prof. Niklas Fanelsa. While they gave us lots of freedom in our project, the regular meetings pushed us to make progress in our project. Moreover, they often came up with concepts to visualize our findings and supported us with helpful material and ideas. We are especially thankful for the contact with Yao Rong, who works with Prof. Dr. Kasneci in the Human-Centered Technologies for Learning group. Her input and ideas on how to create visibility for our project and make an impact were very exciting and she put a lot of work and time into helping us wherever she could.

Furthermore, we had the pleasure of exchanging ideas with Dr. Merle Böhmer and her team from the Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit. Working in the Department of Infectious Disease Epidemiology and especially on tick-borne diseases, namely tick-borne encephalitis, she gave us valuable insights into her research and her interest in our project boosted our motivation.

In conclusion, we all learned a lot at TUMJA working on the Tick Talkers project and enjoyed our time, although we have some suggestions for improvement to help future scholarship holders profit even more from TUMJA.



POSTER 1:

During the first few months of our time at TUMJA, we participated in workshops to help us define our project. We came up with the idea of a topic related to climate change and the spread of a disease. After several discussions about more 'exotic' diseases such as dengue fever or malaria, we finally decided on Lyme borreliosis as it is already more present in Germany and therefore more relevant and tangible for the general public. Initially, we wanted to improve supply chains in the medical sector. We wanted to be able to predict the incidence of Lyme borreliosis and thus the need for antibiotics. However, we soon realized that this was a complex process and shifted our focus to informing the general public.

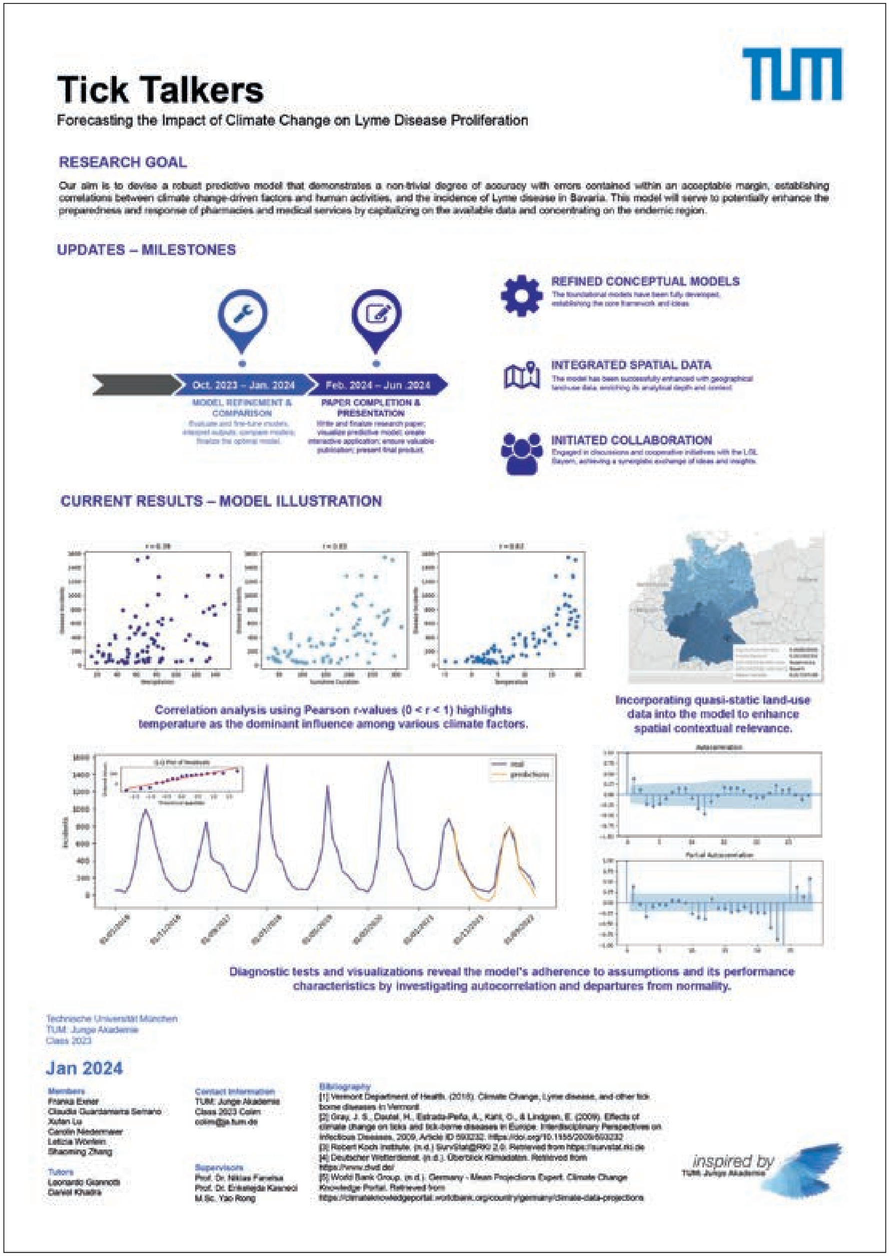
After deciding on our topic and goal, we spent the first few months researching the life cycle and reproductive behavior of ticks and the transmission process of Lyme disease from an infected tick to a human. ■

POSTER 2:

To create our model, we identified the following inputs: temperature, humidity, land use, host density and human population. With these, we want to predict the incidence of Lyme borreliosis in Bavaria. We grouped the inputs into different categories in order to implement a multimodal model.

We also created the first graphical representation of the website we planned to build. We wanted to show the risk areas for Lyme borreliosis on an interactive map, where users could choose which greenhouse gas emission scenario and which 10-year time frame they were interested in.

At the same time, we also looked at which scientific journals we could use to publish our final paper. After analyzing several papers and searching various websites about ticks and the impact of climate change on tick-borne diseases, we were able to identify the research gap that our project would fill. We found that no predictive and regional model has been developed yet and that our model can add significant value.. ■

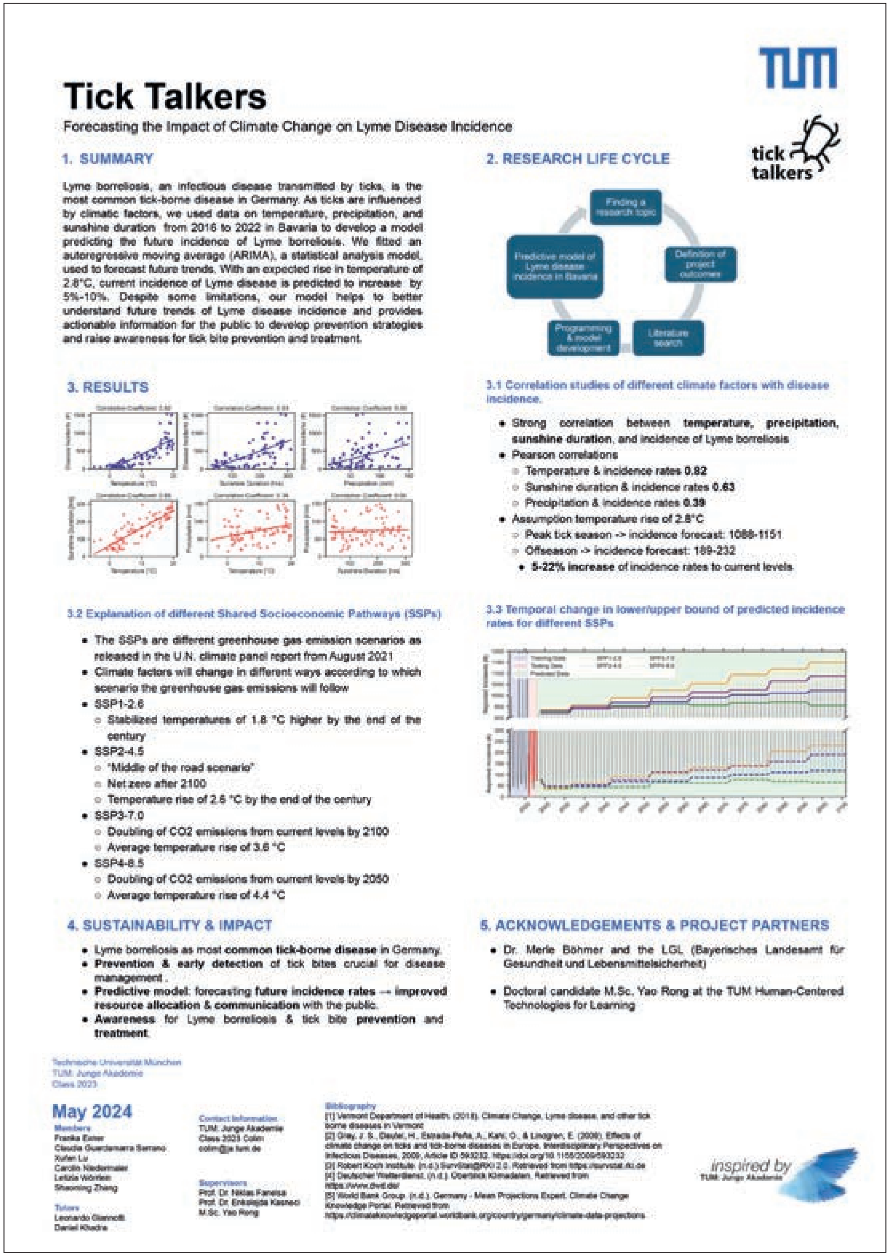


POSTER 3:

The correlation of the following variables with the incidence of Lyme borreliosis was evaluated: precipitation, sunshine duration, and temperature. We concluded that a strong correlation of the incidence with all three factors, and especially temperature, seems to have a high influence on the spread of Lyme borreliosis and implemented the first two models. Since the Q-Q plot of residuals indicated that the data is normally distributed, we decided to use advanced linear regression models such as ARIMA to implement two toy models.

Even though we had identified land-use data as a possible input variable and saw that with quasi-static land-use data, our model would better capture the spatial dynamics of Lyme disease, as reflected in the autocorrelation analysis, we eventually decided not to utilize it in the model. This was because land usage is a variable that only marginally changes in shorter time frames and we weren't able to find predictive land use data. Furthermore, we encountered some difficulties mapping the land use to each Landkreis, which is the basis for the incidence data. Therefore, we decided to use the land use data only as an additive piece of information on the website, as displayed on the prototype of the interactive map, which was built using Tableau.

We also started a collaboration with the LGL (Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit) to widen the impact on the target population and gain a better insight into the topic.



POSTER 4:

The emphasis was on cleaning the prediction data and implementing the predictive part of our model. We first encountered some unexpected results but soon found the mistake in our code. As the effect of climate change and the impact and differences between the four different greenhouse gas emission scenarios were more strongly visible in the second half of the twenty-first century, we decided to show the prediction of all four scenarios up until 2100 instead of only 2050. We did see a strong increase in the incidence of Lyme borreliosis in the next decades, especially in the SPF-8.5 scenario.

At the same time, we began writing our journalistic and scientific reports. Team research progressed quickly and with Mr. Fromm's feedback, we were able to adapt our style and content to produce an interesting news article.

During the final part of the project, we continued to write the paper, which we expect to publish in the autumn, after our official TUMJA time. We also developed the video presentation for the symposium and finished writing the various sections of the research report required by the official TUMJA body.