Cow Social Interaction and Disease Transmission

Final report from our project on improving health and production in dairy cattle

Cow Social Interaction and Disease Transmission
Year of publication: 2024
Publisher: SLU, Department of Animal Biosciences
Text and layout: Lisa Beste
Cover photo: Ida Hansson
Printing: SLU Grafisk Service
Paper: Cover: Xerox Colotech + 200g, text section: Xerox Colotech + 120g

Content

Project leaders' perspective

By combining insights from multiple disciplines, the Cow Social Interaction and Disease Transmission (CSI:DT) project has significantly advanced our understanding of disease transmission and uncovered new findings about the impact of social bonds among dairy cows. Running from 2020 to 2024, the project was funded by the research council Formas and the Beijer Foundation. Enjoy this popular science project report.

The pandemic almost stopped us from performing our planned research, since it involved researchers in Sweden and Denmark, and there were strict traveling restrictions between our two countries. Nonetheless, we collected an unprecedented data set with positioning data over three years on all cows from two farms as planned, one in Sweden and one in The Netherlands. Our collaborators at Copenhagen University collected milk samples from all cows on the Swedish farm, every second week over four months in 2020, to investigate pathogens known to cause mastitis and track how these pathogens are transmitted between cows.
"Leading this exciting research project on dairy cows has been a pleasure. The way cows interact in free-stall farms impacts production and disease transmission. The pandemic, from 2020 to 2022, made people aware of the importance of understanding how social contacts affect disease transmission, and it has therefore been easy to communicate the importance of our research project to the general public," says Lars Rönnegård, professor in statistics at Dalarna University, and project leader.

An interdisciplinary project

We have worked together with several young researchers that have added an amazing amount of energy to the research and novel ideas. It has been an interdisciplinary project where the researchers have a background in animal behaviour, genetics, veterinary science, epidemiology, engineering, and data science. This mix has helped us complete a rather ambitious project and we have come up with many new ideas for future research.
The research project would not have been possible without the collaboration with the farmers letting us collect data at their farms, and it would not have been possible if they had not shared their experience and expertise with us. We are sincerely glad to have had this collaboration.

Project participants. Top row: Lars Rönnegård, Matti Pastell, Piter Bijma, Hector Marina, Per Peetz Nielsen. Middle row: Svenja Woudstra, Maya Gussmann, Keni Ren. Bottom row: Ida Hansson, Carsten Kirkeby, Volker Krömker. PHOTO: LISA BESTE

"One of the results that stands out concerning social interaction between cows is how the bonds created between cows in early life, the first 14 days after birth, are so strong that they even continue to have more social interaction later in life compared to other cows, something we call the kindergarten effect. This has never been observed before and gives us a whole new perspective on social bonding in animals," says Per Nielsen, ethologist and senior scientist at RISE.

Our goals and findings

Goals of the project

Our goal with this research project was to investigate the possibility to select for increased milk yield considering effects of social interactions between cows, and thereby also improve the social environment of the cows. Current breeding programs in dairy cattle focus on ranking individual cows on their genetic merit, whereas the idea of this project was to investigate the possibility of including social indirect genetic effects in future breeding programs.
Our goal was also to use the location and movement of the cows to investigate disease transmission, and to develop an existing simulation model of spread and control of mastitis-causing pathogens. The long-term aim was to produce knowledge that can aid veterinarians and epidemiologists in understanding how intramammary infections are transmitted and how cows should be treated to reduce mastitis in a herd.

Our main findings

Social interactions and preferences

- We investigated where cows prefer to lie down in the two free-stall farms included in our research project. We found that older high-parity cows occupy cubicles close to the feeding table and milking area, whereas younger low-parity cows occupy cubicles further away from the feeding table and milking area. In general, cubicles close to the feeding area are occupied the most and seem to be the most popular.
- We analysed which other cows a cow tends to have contact with during a day. We found a "kindergarten effect" where cows of the same age, raised together as calves, tended to hang out together as adult cows in the barn. We also found a "motherhood effect" where mothers tend to be close to their adult daughters in the barn. This motherhood effect was surprising since the mother and daughter are separated shortly after birth. This knowledge could be important for the farmers when they decide which cows to keep together in the barn.

In a novel study on mastitis pathogens we investigated two important families of bacterial species: Corynebacterium and Staphylococcus.

- We were able to describe where *Corynebacterium* species can be found in a barn. Several of the species, causing intramammary infections, were found in the housing environment. But the dominant bacteria causing masititis, *Corynebacterium bovis*, could not be found in the environmental samples. Therefore, our study indicates that environmental reservoirs are of little relevance in this case.
- In our study on *Staphylococcus* we were able to give a much clearer picture of strain diversity and infection durations than previous studies. This new knowledge is important to understand how intramammary infections are transmitted and how cows should be treated to reduce mastitis in a herd.

Organisations participating in the project CSI:DT, Cow Social Interaction and Disease Transmission.

Social interactions, animal welfare and milk production

Cows housed in indoor free-roaming environments, spend their time resting, walking, standing, feeding and visiting the milking robot. Understanding their behavior patterns and social interactions is crucial for promoting cow welfare and preventing disease outbreaks. Here, we meet PhD student Ida Hansson and postdoctoral researcher Hector Marina, who are studying these dynamics.

By monitoring dairy cows, we have gained valuable insights into the animals' behavior and social interactions. This knowledge can be applied to improve livestock farming, particularly in enhancing animal welfare and health.

Cows exhibit a range of movement patterns. They walk short distances, stop, turn around, and change direction. Occasionally, they may take longer walks within the barn, but much of their time is spent resting. In the feeding area, cows tend to move back and forth within a limited space as they eat and socialize within the group.

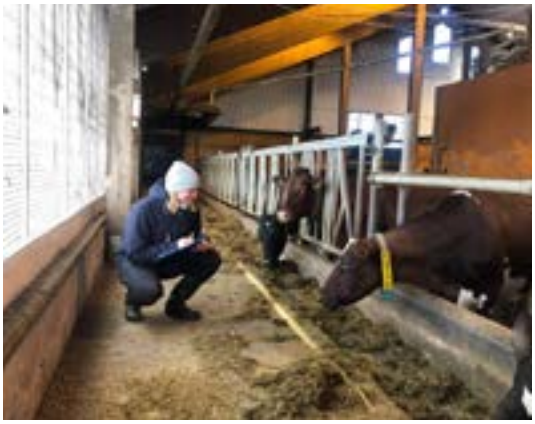
In modern barns where dairy cows can roam freely, certain areas – such as the waiting space in front of the milking parlor – can become quite busy, with cows interacting as they wait for their turn.

In one of our studies, agronomist and PhD student Ida Hansson, along with veterinarian researcher Svenja Woudstra (see pages 8-9), has identified notable patterns regarding how cows enter the milking parlor. Their research indicates that low parity (number of calvings) cows and those in early lactation tend to enter the milking parlor earlier than higher parity cows and those in late lactation. Since the milking parlor is a critical area for disease transmission – particularly for conditions such as mastitis – this knowledge can help farmers implement strategies to mitigate risks for diseases.

Why do the cows behave this way?

The fact that the early lactation cows show a different behavior than cows in later lactation, may be linked to their time spent within the group and their familiarity with the other cows. This familiarity appears to influence the number of interactions these cows have with each other. Consequently, it could also explain why early lactation cows display behaviors similar to those of low-parity cows.

"We know from previous studies that cows within the same parity tend to spend more time together, so it is possible that they move to the milking parlor as a group. Another theory is that young cows are more eager to enter the milking parlor as soon as possible, to escape the crowded waiting area," says Ida Hansson.



Ida Hansson, PhD student in the project Cow Social Interaction and Disease Transmission.
PHOTO: ANNA SILVERA

Our research combined hands-on work in the barn with in-depth data analysis using computer modeling. From left to right: Svenja Woudstra, Hector Marina, Maya Gussmann, Keni Ren, and Teresa Johansson.
PHOTO: HANNA JOHANSSON

In most herds, younger cows tend to have lower infection rates from contagious mastitis pathogens compared to older cows, and the order in which cows are milked may play a role in this. Understanding that cows don't mix in a random order is a crucial piece of the puzzle when studying the spread of pathogens.

In one study within the project, real-time location data was used to monitor the behavior of dairy cows, focusing on how individual characteristics influence their social interactions in feeding and resting areas. Ida Hansson and her colleagues investigated if lactation stage, parity, breed, pregnancy status, estrus, udder health, and claw health affect the number of contacts. They found that cows differ in their tendency to be close to each other and that lactation stage and parity, in particular, influenced the number of contacts.

Postdoctoral researcher Hector Marina has provided valuable new insights into social relationships among dairy cows, examining how factors like time of birth, parity and relatedness (parental or half-sibling connections) affect their spatial interactions later in life.

"We have observed that cows that are born around the same time and grown up together tend to form strong bonds. These cows remain close as they mature, sticking together in the barn and seeking each other's company. We have also noticed a tendency for cows to spend more time with their parental and half-sibling relatives," Hector Marina says.

He is fascinated by how cows on farms behave and interact within dynamic social networks. He finds it rewarding to contribute knowledge that enhances our understanding of cow behavior, ultimately helping to ensure the health and well-being of dairy cows and reduce their stress. This research also aims to optimise the layout of barns and ensure smoother herd management for farmers.

So far, the project team has concentrated on studying free-roaming cows in indoor environments.

"In the future, we plan to expand our research to explore how social interactions impact the animals' well-being and health in outdoor settings, using a broader range of techniques to gather data on cows interactions and movements," says Hector Marina.

Promoting health, preventing diseases

In dairy cows, mastitis, the inflammation of the udder tissue, is a prevalent condition which is typically due to bacterial infection. This disease represents one of the most significant economic challenges in the dairy industry, as it adversely affects both cow health and milk production and quality. Consequently, it is a primary focus of our research team. Here we meet Svenja Woudstra, a veterinarian and researcher involved in our project.

Mastitis occurs when specific bacteria enter the cow's udder through the teat canal. Cows can be exposed to these bacteria for example via bedding material, manure, and milking equipment. Contagious mastitis is believed to be transmitted during the milking process. For instance, if a cow is milked immediately after another cow that has an infection, there is a risk that the second cow could become infected due to bacteria from the first cow on either the milker's hands or the milking liners.

Svenja Woudstra is an assistant professor at the University of Copenhagen, specialising in mastitis infections. Her research focuses on mastitis epidemiology and controlling intramammary infections, which is critical for improving animal welfare and enhancing farm productivity.

Svenja, under the supervision of Professor Volker Krömker, together with her colleagues conducted an investigation to identify where *Corynebacterium* (*C.*) species can be found within the housing environment of dairy cows.

By collecting a variety of samples from different locations around the barn, our researchers were able to demonstrate that many *Corynebacterium* species frequently reside in areas such as the bedding material and on the floor in front of the drinking trough as well as surfaces related to milking. Interestingly, *C. bovis*, the species most relevant to intramammary infections, was not detected in any of the environmental samples.

Environmental samples collected from the barn.
PHOTO: NICOLE WENTE

"As far as we know this is the first study to describe where *Corynebacterium* species can be found within the barn environment. We discovered that several of the species capable of causing intramammary infections were indeed present in the housing environment. However, the most significant *Corynebacterium* species responsible for masititis, *C. bovis*, was notably absent from the environmental samples we collected. This finding suggests that, at least in this case, the environment is not a primary source of infection, which could have implications for how we approach the prevention of mastitis in dairy herds moving forward," Svenja Woudstra says.

Why is this important?

"In mastitis research we distinguish between two main modes of pathogen transmission, those transmitted directly from cow to cow and those that result from pathogens present in the environment. Understanding this distinction is crucial because it helps us implement more effective prevention and management strategies in dairy farming. By categorising bacteria into one of these groups, we can tailor our approach to reduce the risk of infection and eventually improve animal health and welfare. However, our research and that of others have demonstrated that transmission modes of the same species might differ between herds. Therefore, we know today that it is necessary, for at least some bacterial species, to investigate their transmission behaviour within a specific herd, for example via strain typing, to adopt the appropriate measures."

Media used for microbiological analysis.
PHOTO: NICOLE WENTE

How will you proceed with this knowledge?

"The next logical step would be to compare strains of *C. bovis* found in different cows to determine whether the same strains are present across the udder quarters of multiple cows. If we find identical strains in different cows, this would strongly suggest that *C. bovis* is spreading from cow to cow, likely during the milking process. This would provide clear evidence of cow to cow transmission, which would be important for targeting control measures," Svenja Woudstra says. She is working towards facilitating the identification of transmission pathways for mastitis-causing bacteria in the cows' environments. By gaining a better understanding of how these bacteria spread, she hopes to contribute to the development of more effective strategies to minimise the transmission of infections.

In the project, also the transmission pathways of other pathogens have been further investigated as well as the duration of untreated intramammary infections. Data on the latter is scarce in the scientific literature. However, only infections with a low rate of spontaneous cure will benefit from antimicrobial treatments. We found in our study that many infections with non-aureus staphylococci have a very high self-cure rate. Intramammary infections with at least some of the non-aureus staphylococci species are therefore likely not benefiting from antimicrobial treatment. This must be investigated further in larger studies collecting samples from more herds. These new insights might contribute to a more prudent use of antimicrobials in dairy herds in the future.

Svenja Woudstra, veterinarian and researcher, did her PhD within the project CSI:DT, Cow Social Interaction and Disease Transmission.

Modelling and statistics

Keni Ren, electrical engineer, and Maya Gussmann, mathematician, have played key roles in improving the accuracy of the real-time monitoring systems and the statistical models to explore cows' social networks and the spread of mastitis.

Improving dairy cow monitoring systems

Keni Ren is an electrical engineer who completed her postdoctoral research as part of our project. "My primary focus has been on understanding how the sensors we use to monitor cow behavior function, and occasionally, why they malfunction. I evaluate the system we rely on and verify the accuracy of the data," she explains.

Together with her colleagues, Keni Ren has developed a highly accurate method for interpolating missing data in dairy cow monitoring systems. This advancement can significantly enhance the precision of indoor positioning systems used by modern farms and researchers to analyse the behavior and activities of cows within barns.

Real-time systems for monitoring animals, e. g. ultra-wideband (UWB) technology, are increasingly used but not perfectly accurate. Almost always, there will be a lot of time-gaps in this kind of studies, where data are missing due to physical structures in the barn, calibration problems or communication failures between the tags carried by the cows and the receiver anchors in the locating system.

In the field of statistics there are a number of interpolation methods used to improve the quality of data sets, by predicting and estimating the unknown data. Keni Ren and her colleagues decided to find out which interpolation method would be the most accurate one to use when studying the positioning data for dairy cows inside a free-stall dairy farm.

"We investigated four types of methods. All four are well known methods but we didn't know how much they differ or which one to prefer in the application with real cow life," Keni Ren says.

The positions of individual dairy cows were tracked using a monitoring equipment including tags placed around the cows' necks. PHOTO: IDA HANSSON

The modified Akima method was the best one

Over six days, 69 cows were closely observed to analyse where data gaps occurred and how long they lasted. Data from the 20 most reliable tags were then compared with interpolations, of simulated missing data, from four different interpolation methods: (1) previous position, (2) linear interpolation, (3) cubic spline data interpolation, and (4) modified Akima interpolation.

”The modified Akima interpolation method showed the lowest error distance for all investigated cow activities; walking, feeding, resting, and standing. In other words, it had the highest prediction accuracy across the different activities in the barn,” says Keni Ren.
The algorithm in the modified Akima interpolation method is designed to prevent overshoots while avoiding excessive flattening, making it well-suited for capturing various movements within the barn.
The Akima method outperformed the others, particularly in filling gaps when cows were walking.
”I was surprised by how quickly the error distance stabilized after just one minute of missing data with this method,” Keni Ren notes.
Validating the system is crucial as it forms a solid foundation for the ongoing observation of cows' social interactions. This comprehensive validation will benefit not only other researchers in the field but also farmers who rely on accurate monitoring systems.

Understanding mastitis transmission through statistical models

Maya Gussmann is a mathematician and researcher who has been working with statistical modelling in our project.
”My primary contribution was developing models for the milking order on dairy farms and the spread of mastitis related to this order,” she explains.
Most previous studies in this area were conducted on small experimental farms over short periods. By studying cows on two real commercial farms, Maya Gussmann and her colleagues discovered new insights.
”We observed that when cows were regrouped, behavior changes were less pronounced in larger groups compared to the literature on smaller groups. While we did see some changes before and after regrouping, they were less dramatic than expected. In smaller groups, cows tend to eat more, rest less, and move around more after regrouping,” she explains.
Maya Gussmann believes it would be valuable to explore the reasons behind this difference.
“It might be that the regrouping doesn't matter for the cows in the large group that much because there are used to facing unknown cows. The change will not make them stressed. Another theory could be that cows in a larger group are more stressed in the first place and therefore you don't see the difference in behaviour before and after regrouping,” she suggests.

Calibrating mastitis models: rethinking milking order impact

Calibrating statistical models to reflect real farm conditions is challenging. According to our project's findings, the ”baseline” for cow behavior shouldn't assume a completely random order.
”Logically you would expect that if a cow diseased with mastitis are milked first, the cows that comes to the milking place after that will be transmitted and you would see an increase in the number of sick cows. Initially, my model indeed showed a large increase in mastitis transmission when an infected cow was milked first. However, after calibrating the model to resemble real farm conditions, the difference between milking order scenarios - whether the infected cow was milked first or last - became less significant,” she says.
Ultimately, maintaining good barn hygiene remains the most effective way to prevent disease spread, a conclusion that is not new but still essential to emphasize.

You find more information about our project here:

Insights from stakeholders

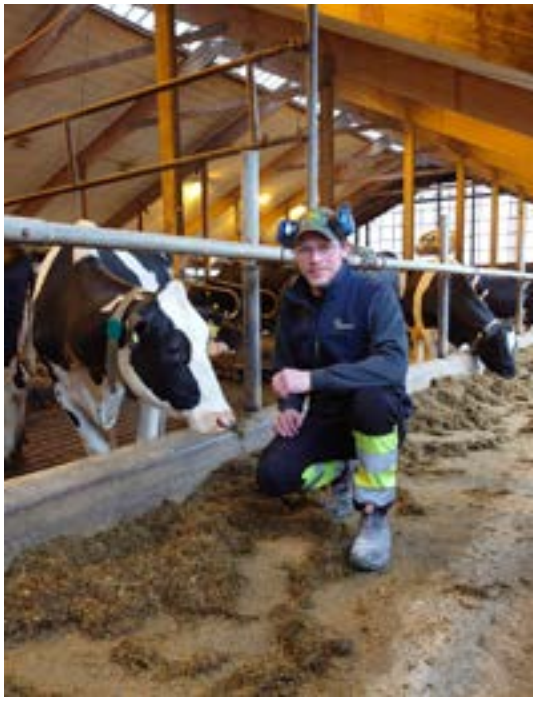
Throughout the four-year project, we analysed data from two dairy farms - one in Västra Götaland County in Sweden, and one in the Netherlands. We developed methods to study the cows' social networks, health, and welfare in relation to milk production. In this section, we gathered insights from a farmer and a veterinarian on their perspectives regarding the research.

A farmer's viewpoint

Fredrik Larsson contributed to our project as a dairy farmer on one of the two farms where we observed the social networks of cows.

Why is it important to study dairy cows' behavior?

The more we understand about cows, the more research can drive meaningful improvements on farms. Animals' well-being is closely tied to production goals. High milk production simply isn´t possible without cows that are healthy, calm, and thriving. In my opinion, the highest standards of animal welfare equals the best milk yields.
I think we could actually measure good animal welfare by observing how well the cows produce milk. You can probably get a cow to produce milk at an average level with adequate care, but a too stressed cow won't produce milk at all.



Fredrik Larsson, farmer at one of the dairy farms participating in our project.
PHOTO: HANNA JOHANSSON

Do you see differences in behavior among different dairy cows?

Dairy cows do show some degree of individual personality. However, we aim to have animals that are as similar as possible, both in terms of physical structure and behavior. Consistent behaviour among the cows makes managing them much easier.

What are the most common challenges a dairy farmer faces?

Mastitis, or udder inflammation, is by far the biggest issue. It is, after all, the most common disease in dairy cows.
There are also certain regulations surrounding farming that don't seem beneficial from my perspective. In fact, certain laws may sometimes create problems for production and animal health rather than driving improvements.

What has it been like, for you, to participate in the project?

It has been an enriching experience. We have had many engaging discussions along the way, especially when the researchers were on the farm compiling their data. From my end, my main responsibility has been periodically sending raw data to the researchers for analysis.

Thoughts from a veterinarian

Lisa Ekman works as a veterinarian at Växa Sverige and SLU. She focuses on animal health with a specific interest in sustainable food production, climate adaptation, and the health of dairy cows. She combines research and practical application, particularly aiming to get results useful for farmers.

Her work involves areas like mastitis, epidemiology, animal welfare and stress in dairy cows and its effects on milk production and fertility.

We asked Lisa to share her reflections on the research on cow social interaction and disease transmission.

Why is research on dairy cow behavior important?

Understanding animal behavior is crucial for enhancing both animal welfare and health. By learning to interpret the normal behaviors of cows, we can quickly identify deviations that may signal disturbances or health issues. For instance, early detection of diseases can occur when we recognize how cows typically behave. Additionally, monitoring of dairy cows provides insights that help create a more effective farm management system. This research can lead to the development of decision-support tools and algorithms, that adapt to different behavioral patterns, ultimately improving the working environment for farmers. While significant progress is still needed, the current research on cow social interaction represents a valuable step toward achieving these goals.

As a veterinarian, how do you balance the health and welfare of the animals with the production goals of the farmer?

These two aspects are closely interconnected. Healthy animals that receive proper care are often the most profitable for farmers. However, there are specific situations where trade-offs may be necessary. For example, if a farmer chooses to build a larger barn, it may be more expensive, even though the additional space benefits the animals. In such cases, the immediate benefits of increased space and comfort may not clearly translate to higher milk production, creating a dilemma about where to draw the line.

I find it crucial to identify strategies that enhance both animal health and welfare while also thinking about economic productivity. Research into cow behavior can provide valuable insights, helping us avoid unnecessary interventions and ensuring that decisions support the overall well-being of the animals and the farm's success.

What changes would you like to see in the future?

In my research I work primarily with smaller dairy farms and their unique conditions, which has shaped my perspective. Many of these small farms still keep their animals tethered, and I hope for a future where more of them can transition to loose housing in an economically sustainable manner. A key factor for success in this transition is the development of production systems that prioritize high animal welfare alongside innovative husbandry practices.

For example, implementing new flooring materials can facilitate natural movement, making it easier for cows to lie down and rise comfortably. Additionally, designing barns without stalls can enhance freedom of movement and provide more space per cow. Research on cow behavior can contribute to this improvement.

In addition I hope farmers will be able to secure higher prices for their milk by adopting the best animal management practices.

Lisa Ekman, veterinarian at Växa Sverige.
PHOTO: MIKAEL PROPST/SVA

Publications and publicity

We have presented our project's research findings both scientifically and in popular formats. In addition to the publicity reported here, we have participated at scientific meetings and also held numerous internal seminars and workshops. We expect to publish additional articles related to the project in the near future.

Publications in scientific journals

Churakov, M., Silvera, A. M., Gussmann, M., & Nielsen, P. P. (2021). Parity and days in milk affect cubicle occupancy in dairy cows. *Applied Animal Behaviour Science.*

Hansson, I., Silvera, A., Ren, K., Woudstra, S., Skarin, A., Fikse, W. F., Nielsen, P. P., & Rönnegård, L. (2023). Cow characteristics associated with the variation in number of contacts between dairy cows. *Journal of Dairy Science*.

Hansson, I., & Woudstra, S. (2023). Associations of parity and lactation stage with the order cows enter the milking parlor. *JDS Communications.*

Lücken, A., Woudstra, S., Wente, N., Zhang, Y., & Krömker, V. (2022). Intramammary infections with *Corynebacterium* spp. in bovine lactating udder quarters. *Plos one*.

Marina, H., Fikse, W. F., & Rönnegård, L. (2024). Social network analysis to predict social behavior in dairy cattle. *JDS Communications*.

Marina, H., Nielsen, P. P., Fikse, W. F., & Rönnegård, L. (2024). Multiple factors shape social contacts in dairy cows. *Applied Animal Behaviour Science*.

Marina, H., Ren, K., Hansson, I., Fikse, F., Nielsen, P. P., & Rönnegård, L. (2023). New insight into social relationships in dairy cows, and how time of birth, parity and relatedness affect spatial interactions later in life. *Journal of Dairy Science.*

Ren, K., Alam, M., Nielsen, P. P., Gussmann, M. K., & Rönnegård, L. (2022). Interpolation methods to improve data quality of indoor positioning data for dairy cattle. *Frontiers in Animal Science.*

Ren, K., Bernes, G., Hetta, M., & Karlsson, J. (2021). Tracking and analysing social interactions in dairy cattle with real-time locating system and machine learning. *Journal of Systems Architecture.*

Ren, K., Nielsen, P. P., Alam, M., & Rönnegård, L. (2021). Where do we find missing data in a commercial real-time location system? Evidence from 2 dairy farms. *JDS Communications*.

Woudstra, S., Lücken, A., Wente, N., Zhang, Y., Leimbach, S., Gussmann, M. K., Kirkeby, C., & Krömker, V. (2023). Reservoirs of *Corynebacterium* spp. in the Environment of Dairy Cows. *Pathogens*.

Woudstra, S., Wente, N., Zhang, Y., Leimbach, S., Gussmann, M. K., Kirkeby, C., & Krömker, V. (2023). Strain diversity and infection durations of *Staphylococcus* spp. and *Streptococcus* spp. causing intramammary infections in dairy cows. *Journal of Dairy Science.*

Woudstra, S., Wente, N., Zhang, Y., Leimbach, S., Kirkeby, C., Gussmann, M. K., & Krömker V. (2023). Reservoirs of *Staphylococcus* spp. and Streptococcus spp. associated with Intramammary Infections of Dairy Cows. *Pathogens*.

Popular science publicity

Our project members have presented our research through different channels, with different target groups in mind. We have written news articles for the SLU web as well as been interviewed by magasines, radio etcetera. Here are some examples:

30 September 2022 Lars Rönnegård participated in Forskarfredag which is a national event in Sweden organized as part of European Researchers' Night.

21 December 2022 Hector Marina was interviewed in the newspaper ABC España.

27 May 2023 Hector Marina was interviewed in Veterinärmagazinet.

15 June 2023 the project arranged an outreach event, with invited stakeholders and others participating online.

4 April 2024 Lars Rönnegård was interviewed in the magasine Land.

14 April 2024 Lars Rönnegård was interviewed on Radio P4 Dalarna.

Participants

Alongside long-term members of the project, we have had students working with us from time to time. Here are computer science students Nicky Ristic, Douglas Hedström and Isak Jonsson who used data from our research in one of their courses.
PHOTO: TOMAS KLINGSTRÖM

Lars Rönnegård was the principal investigator of the research programme. Lars is a professor in statistics at Dalarna University and a researcher at the Department of Animal Biosciences at SLU.

Per Peetz Nielsen, researcher at RISE, Research Institutes of Sweden, holds a PhD in Ethology. Per was responsible for the overall management of the project together with Lars Rönnegård and contributed with his expertise in ethology and analysis of sensor data.

Anna Silvera worked as a postdoc in the project with a focus on animal welfare.

Anna Skarin, professor in reindeer husbandry at SLU, contributed with her expertise in animal movement.

Carsten Kirkeby, senior researcher at the University of Copenhagen, was involved in the epidemiological modelling of mastitis pathogens.

Freddy Fikse, employed by Växa Sverige and holds a PhD in Animal Science, worked on the genetic modelling in the project.

Hector Marina, postdoc at SLU, contributed with his competence in social network analysis.

Ida Hansson, PhD student at SLU, worked on social contacts and indirect genetic effects.

Keni Ren, postdoc at SLU, contributed with her expertise in electrical engineering and analysis of sensor data.

Lisa Beste, SLU, was a communications officer in the project.

Maya Gussmann, assistant professor at Copenhagen University was responsible for the modelling and simulating of mastitis transmission between cows.

Mikhail Churakov worked as a postdoc in the project with a focus on data analytics.

Moudud Alam, associate professor in microdata analysis at Dalarna University, contributed with his expertise in statistics.

Natalie von der Lehr, SLU, was a communications officer in the project.

Svenja Woudstra, University of Copenhagen, completed a PhD in the project on mastitis pathogens.

Tariq Halasa, University of Copenhagen, initiated several ideas of the project on epidemiology.

Teresa Johansson, research assistant at SLU, worked on animal welfare and analysis of animal activity.

Volker Krömker, professor in cattle health at the University of Copenhagen contributed with his expertise on mastitis.

SCIENCE AND EDUCATION **FOR SUSTAINABLE LIFE**

The Swedish University of Agricultural Sciences, SLU, has its main locations in Alnarp, Umeå and Uppsala.
SLU is certified to the ISO 14001 environmental standard • Phone:+46 18-67 10 00 • VAT nr: SE202100281701