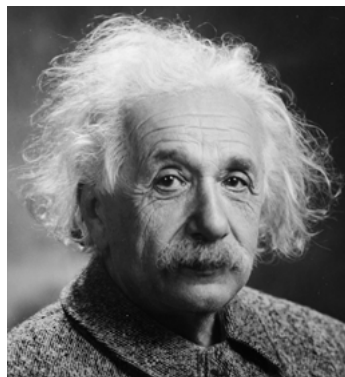


Experiences from seven years of tick-borne encephalitis incidence forecasts in Central Europe

Franz Rubel

7th Labuda's Days, 16–19 June 2025, Stará Lesná, High Tatras/Slovakia

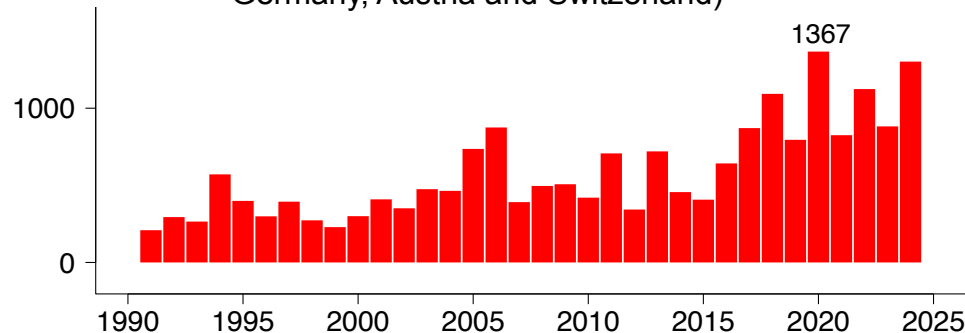
„When our
calculations fail,
we call it
randomness.“



Albert Einstein

TBE incidence in the DACH countries

Germany, Austria and Switzerland)

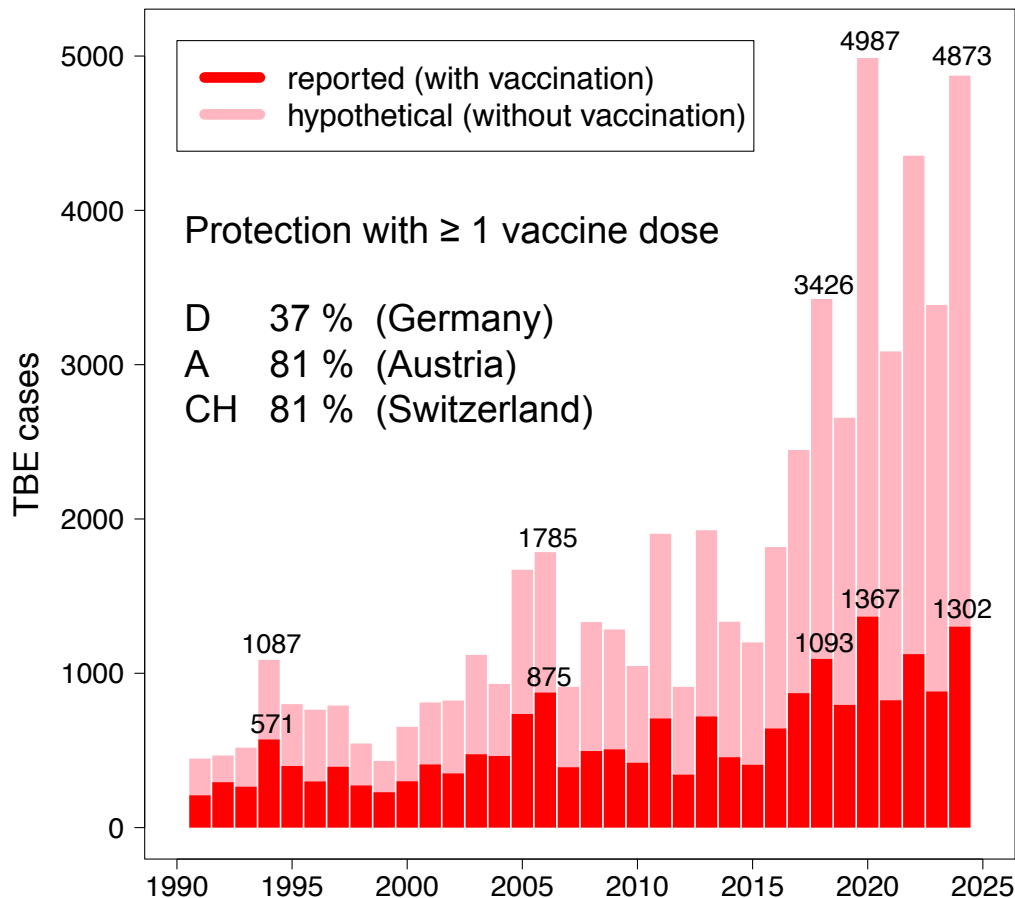


Motivation

TBE incidence has increased sharply over the past three decades, with significant annual fluctuations observed. If the patterns in TBE dynamics are not random, we can make a prediction.

„The capacity to understand disease dynamics and predict disease outbursts is the ‘holy grail’ of infectious epidemiology.“

Peter Zeman, 2017: Epidemiol. Infect., 145, 2781–2786.

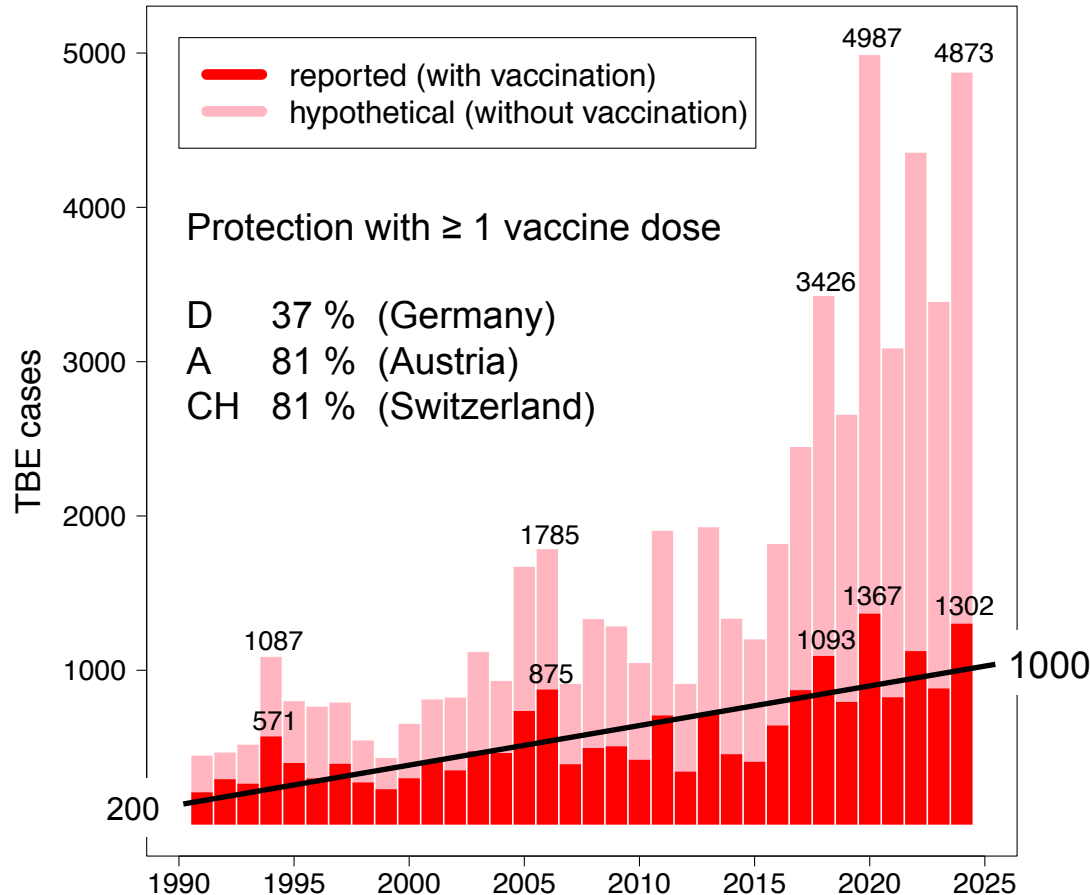


Vaccination coverage

A TBE forecast model must take into account the vaccination coverage of the population, as this reduces the number of cases.

A time series on vaccination coverage (protection with ≥ 1 vaccination dose) was available for Austria, but it needs to be reconstructed for Germany and Switzerland (mainly from grey literature, e.g. studies by the companies Baxter and Pfizer).

More than two-thirds of hypothetical TBE cases in the DACH countries are prevented by vaccination.

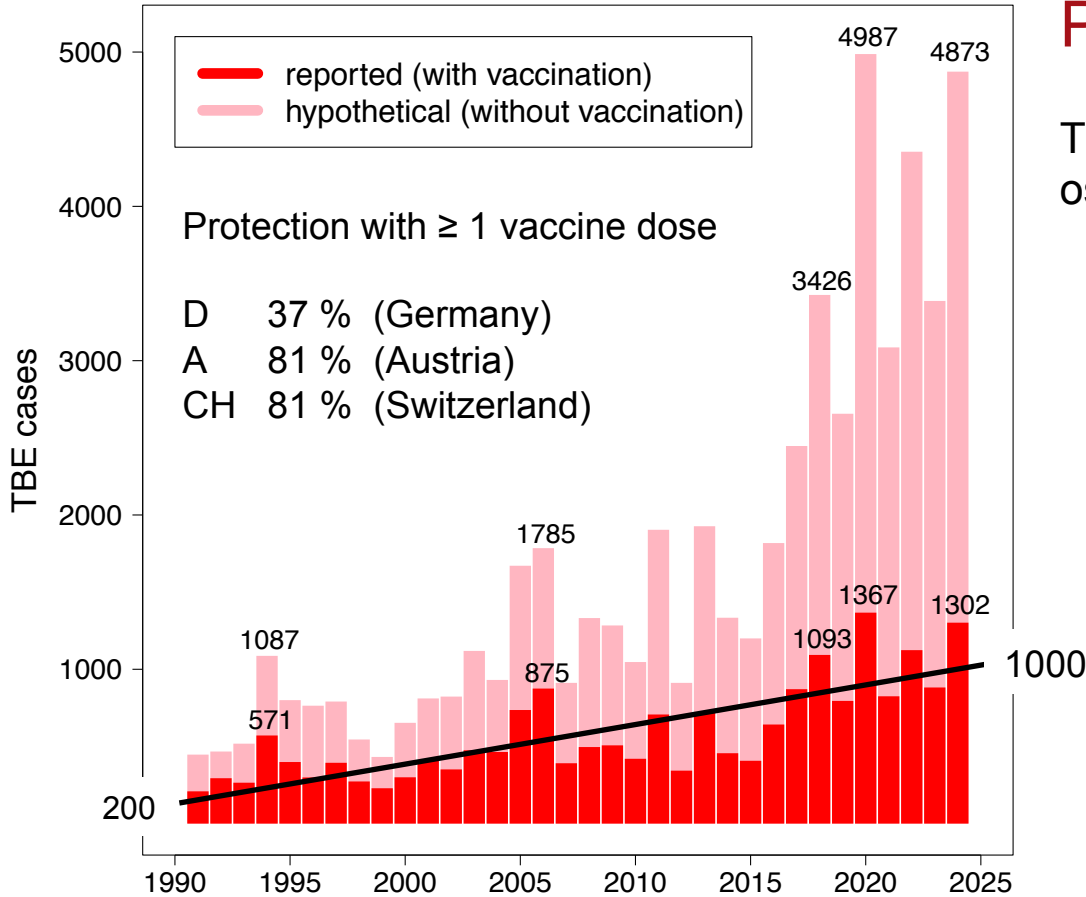


Linear trend

The trend explains 60 % ($R^2 = 0.6$) of the variance of the TBE time series of the DACH countries (Germany, Austria and Switzerland).

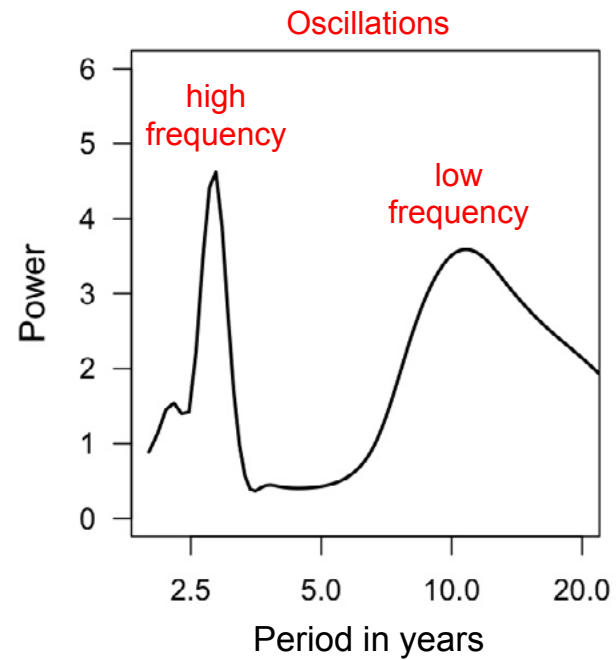
Reported cases in the DACH countries increased from 200 to 1000 during the period 1991-2024 (i.e. during 34 years).

Increase of 23 TBE cases/year



Power spectrum

The trend is overlaid with 3- and 10-year oscillations.



High frequency (3-year) oscillations are determined by masting



Foto: Jiri Bohdal

Yellow-necked mouse (*Apodemus flavicollis*)
Bank vole (*Myodes glareolus*)

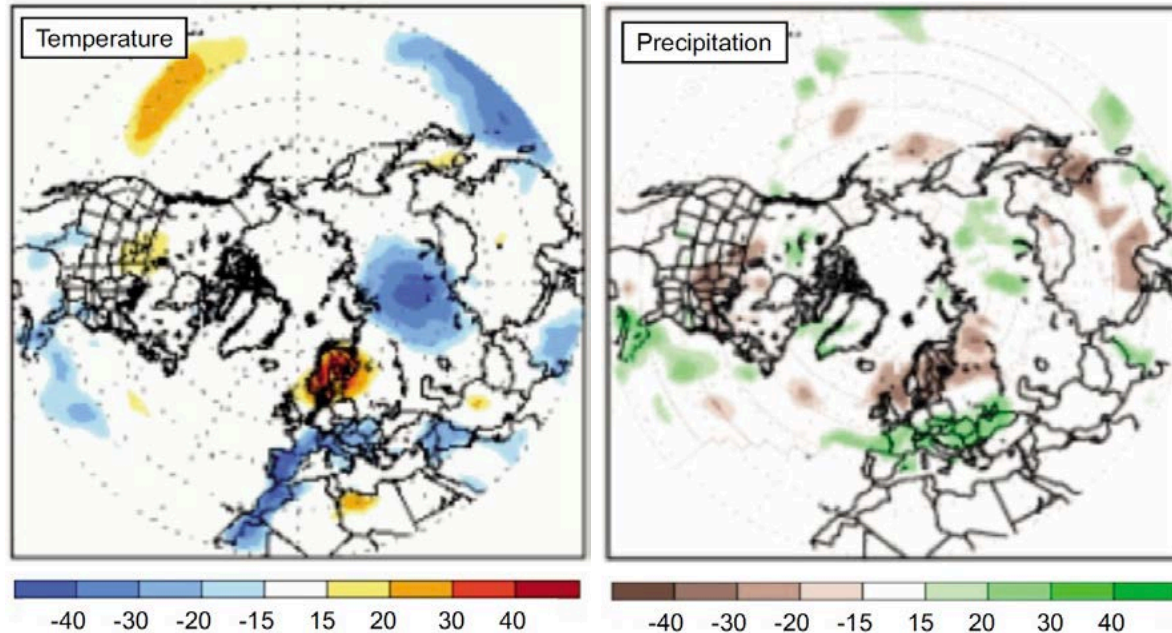
The frequency and intensity of forest tree fructification determines rodent density in the following year and that of *Ixodes ricinus* nymphs two years

later (Brugger et al., 2018). A beech mast index is used here, which distinguish between:



- **No mast:** no/few trees bear fruit
- **Low mast:** only individual trees bear fruit
- **Half mast:** about half of the trees bear fruit
- **Full mast:** all trees bear fruit heavily

Low frequency (10-year) oscillations are determined by atmospheric circulation patterns



Temperature and precipitation anomalies in %.

Scandinavian Index (NOAA)

Best describes the atmospheric circulation in the European TBE distribution area. Alternative: NAO index.

A high Scandinavian Index in July indicates warmer and wetter summers in Central Europe, which favours high tick activity.

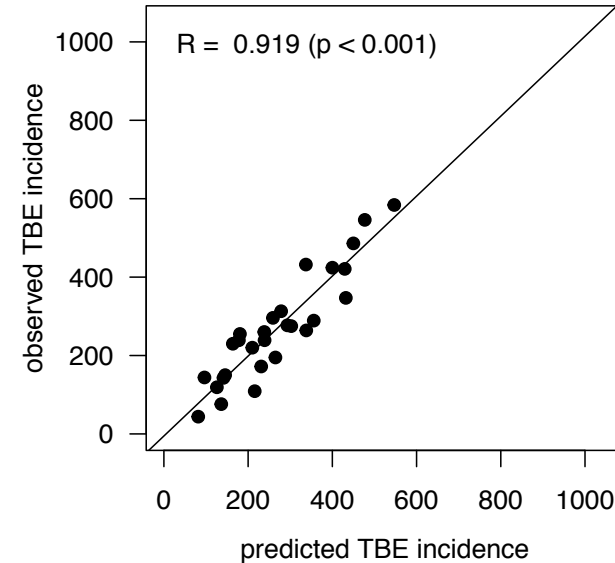
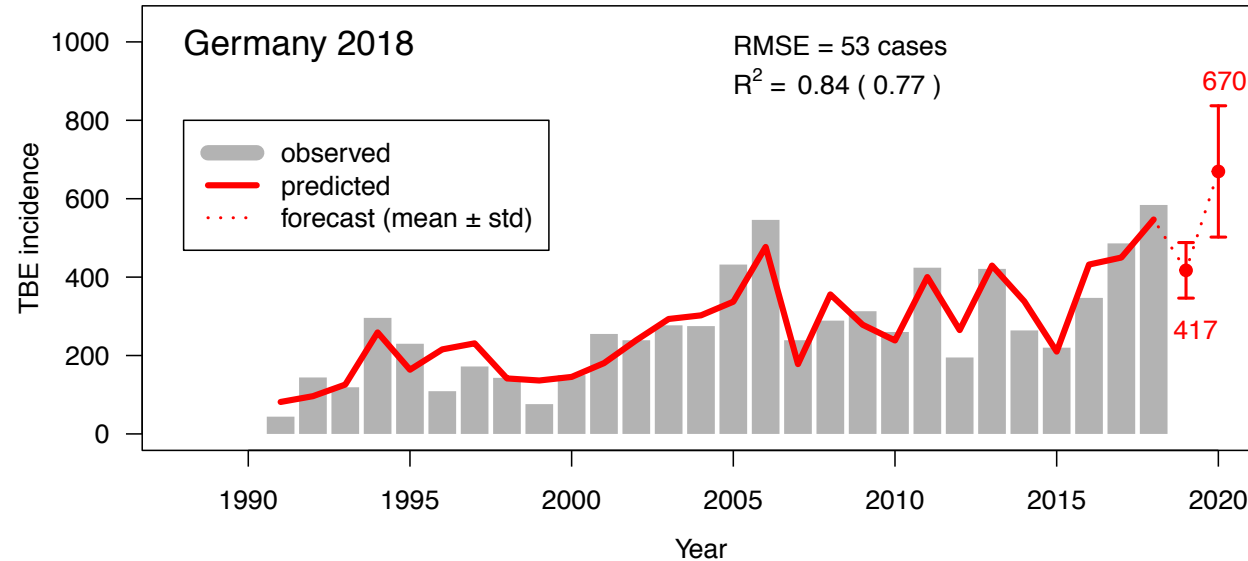
Negative binomial model for TBE prediction (Austria)

$$N_{GLM} = \exp(\beta_0 + \beta_1 N_{TOT} + \beta_2 N_{MIG} + \beta_3 SI + \sum_{i=4}^6 \beta_i F_{year-2,i} + \beta_7 VC)$$

		β	SE	z	p	
	Intercept	0.429	1.124	0.381	0.703	
Total Population	$N_{TOT} \cdot 10^{-6}$	0.790	0.164	4.819	<0.001	***
(indicator of crises) Net Migration	$N_{MIG} \cdot 10^{-6}$	-5.728	1.618	-3.540	<0.001	***
Scandinavian Index	SI	2.229	0.602	3.701	<0.001	***
Fructification, low mast = 1	$F_{year-2} = 1$	0.247	0.084	2.934	0.003	**
Fructification, half mast = 2	$F_{year-2} = 2$	0.355	0.108	3.278	0.001	**
Fructification, full mast = 3	$F_{year-2} = 3$	0.406	0.095	4.268	<0.001	***
Vaccination Coverage	VC	-5.283	0.736	-7.177	<0.001	***

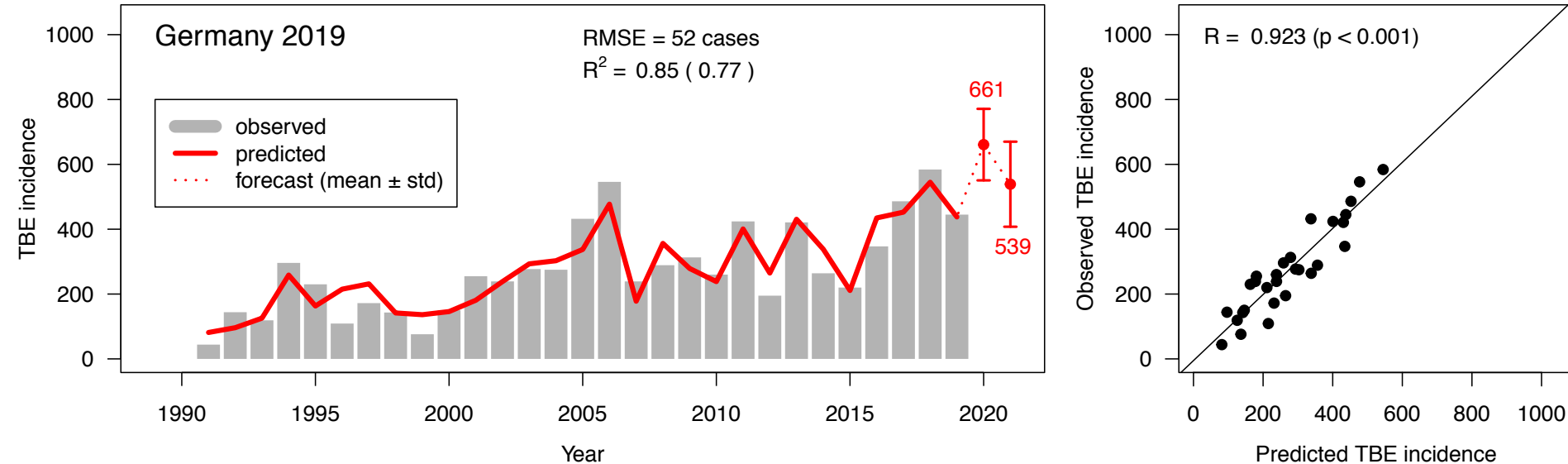
The model takes into account overdispersion, the persistence assumption for unknown predictors of the forecast period, and stochastic error estimation.

Germany: TBE forecast 2018 for the period 2019-2020



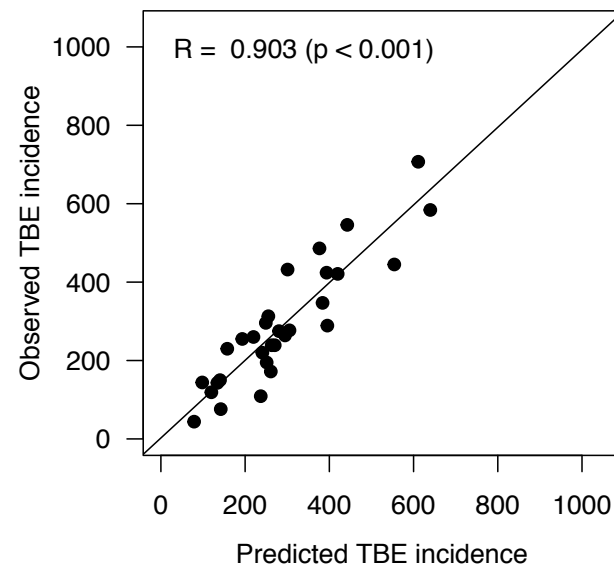
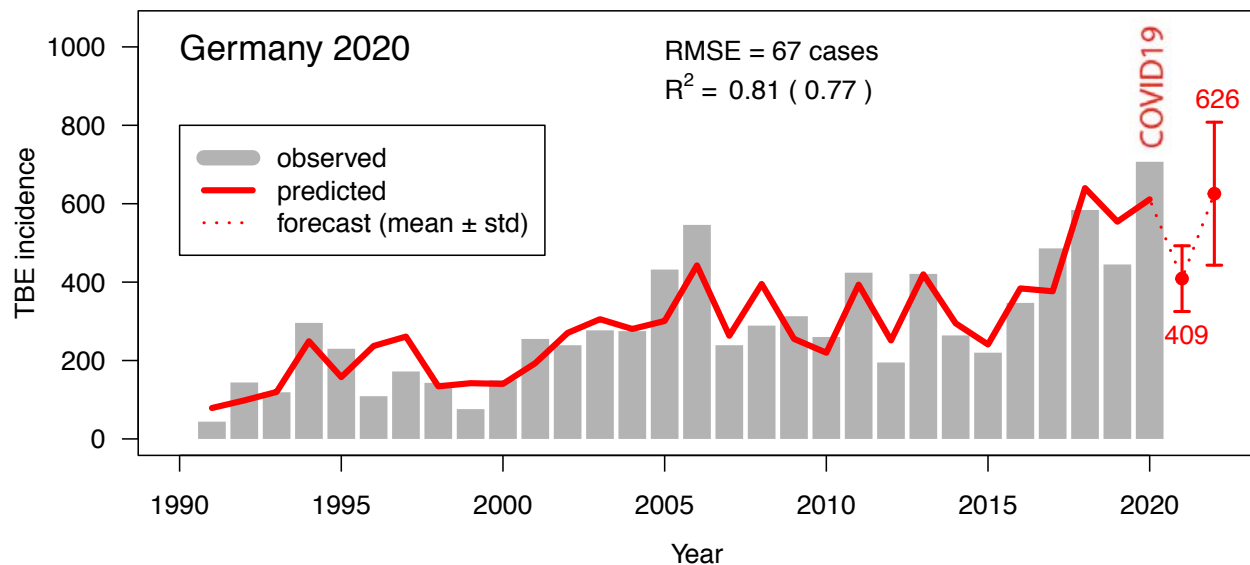
The TBE forecast model is always applied to a 30-year period. The model is calibrated using the TBE cases of the first 28 years (see scatter diagram), and a stochastic forecast is calculated for the two subsequent years.

Germany: TBE forecast 2019 for the period 2020-2021



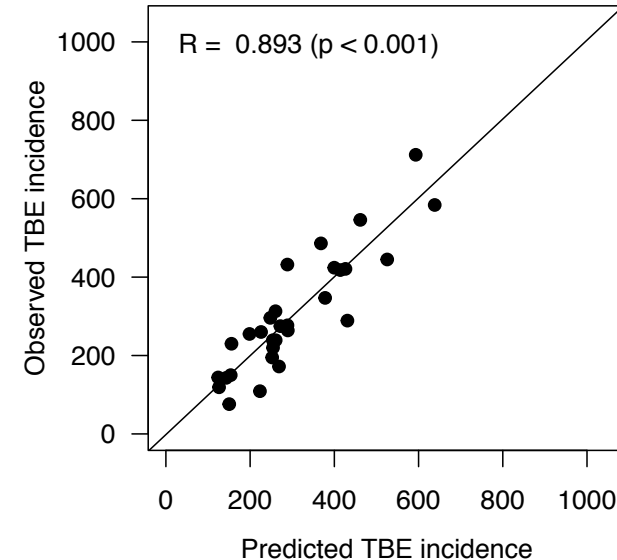
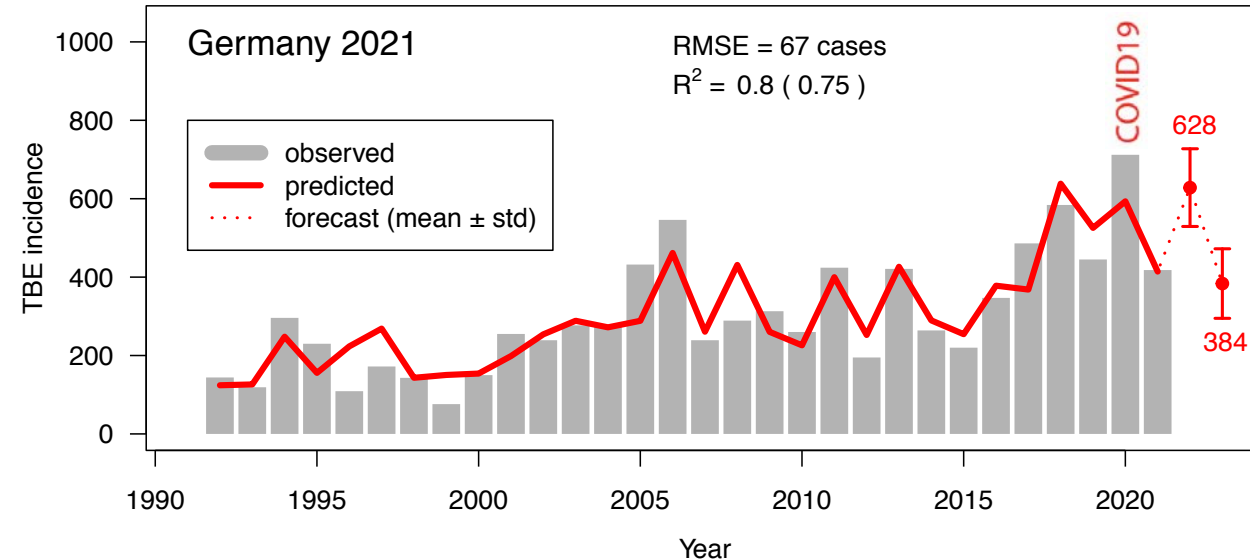
The TBE forecast model is always applied to a 30-year period. The model is calibrated using the TBE cases of the first 28 years (see scatter diagram), and a stochastic forecast is calculated for the two subsequent years.

Germany: TBE forecast 2020 for the period 2021-2022



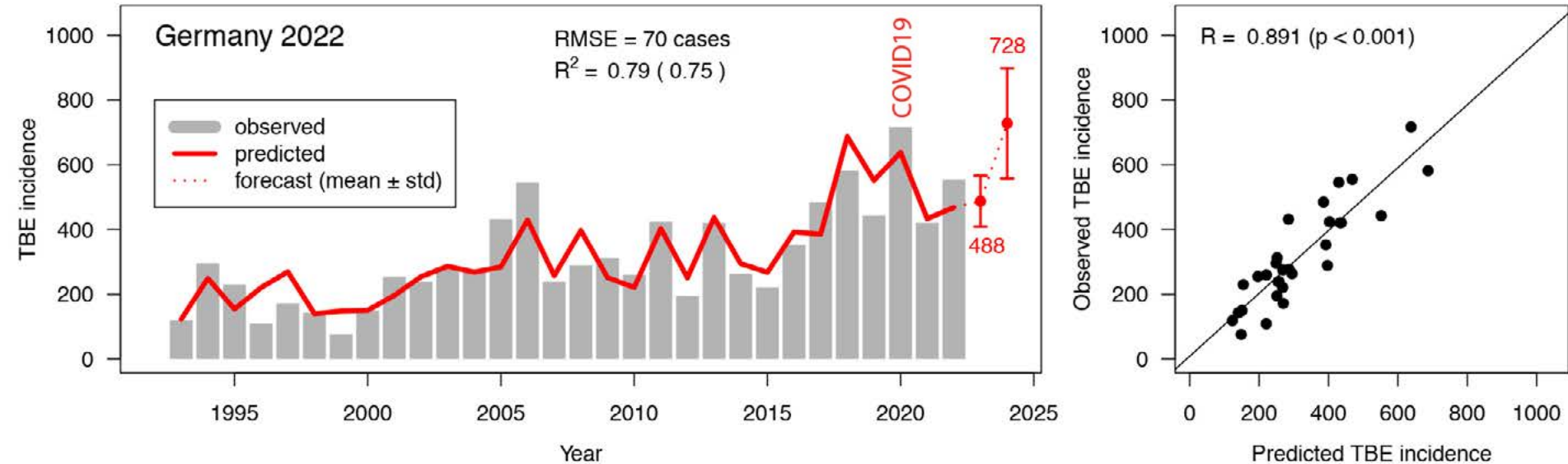
The highest number of TBE cases was observed during the **COVID-19 pandemic**. This is a result of the **coincidence of the 2018 full mast and a change in people's behaviour** (visiting recreational areas instead of work during the 2020 lockdown).

Germany: TBE forecast 2021 for the period 2022-2023



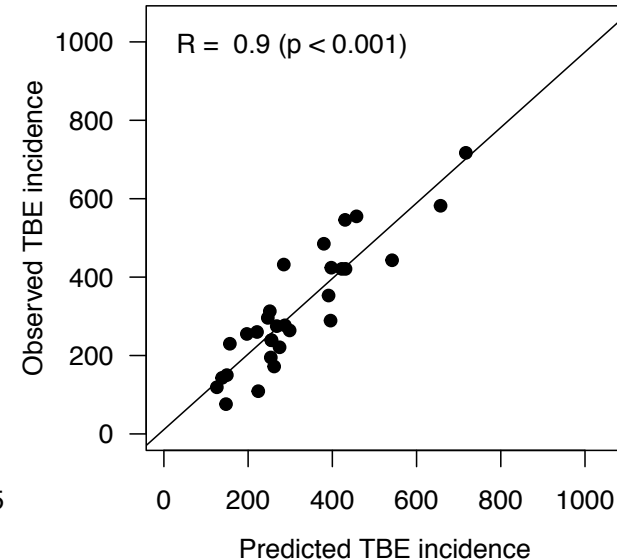
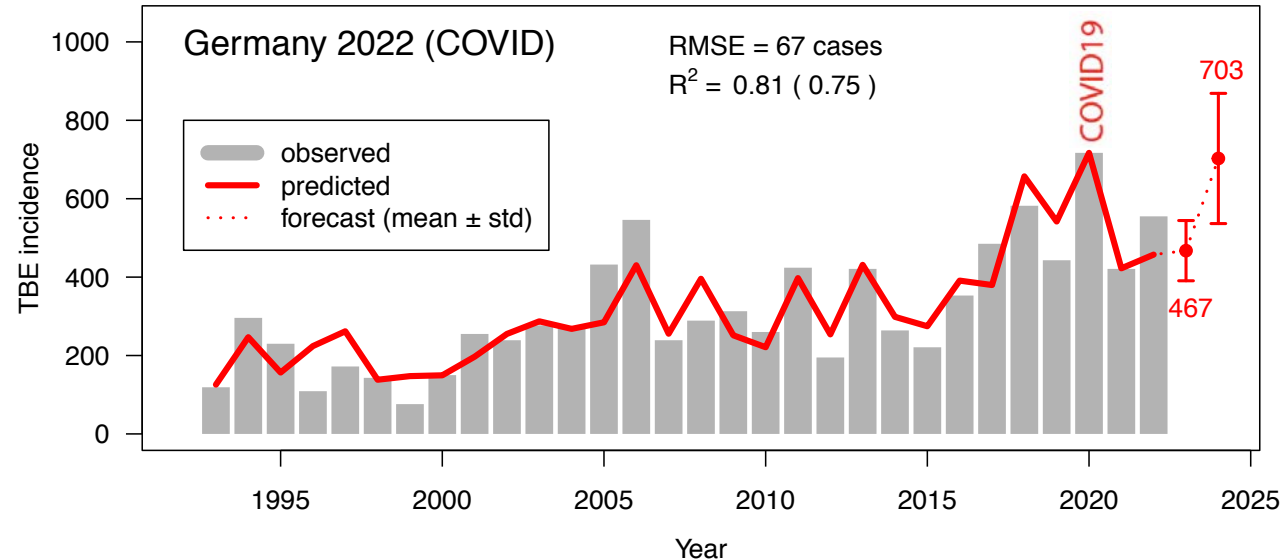
The highest number of TBE cases was observed during the **COVID-19 pandemic**. This is a result of the **coincidence of the 2018 full mast and a change in people's behaviour** (visiting recreational areas instead of work during the 2020 lockdown).

Germany: TBE forecast 2022 for the period 2023-2024



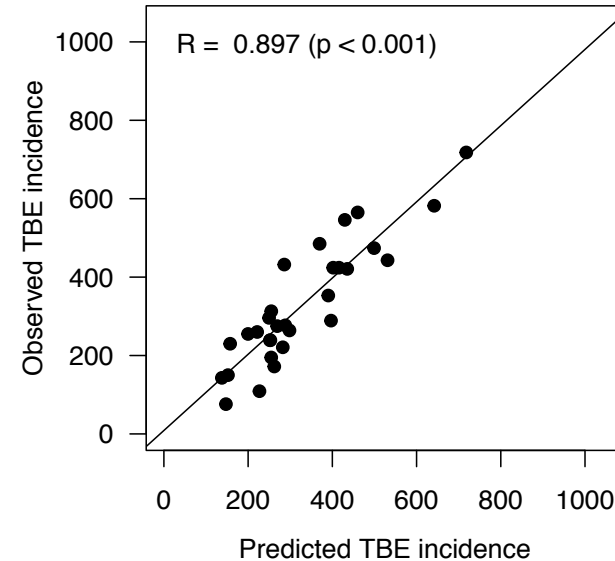
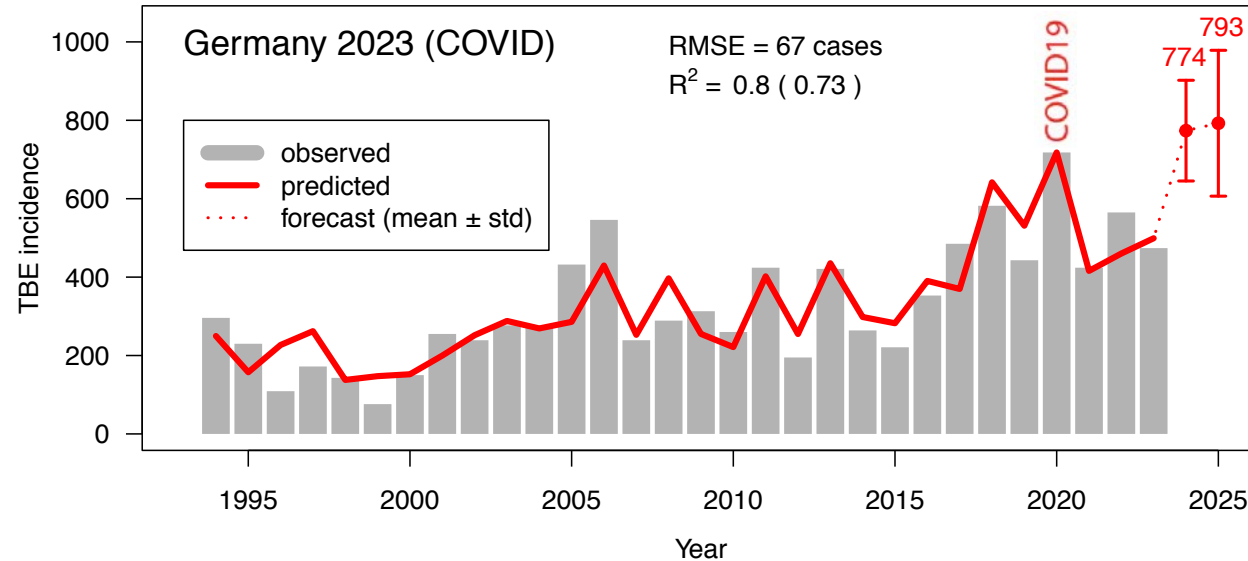
The highest number of TBE cases was observed during the **COVID-19 pandemic**. This is a result of the **coincidence of the 2018 full mast and a change in people's behaviour** (visiting recreational areas instead of work during the 2020 lockdown).

Germany: TBE forecast 2022 for the period 2023-2024



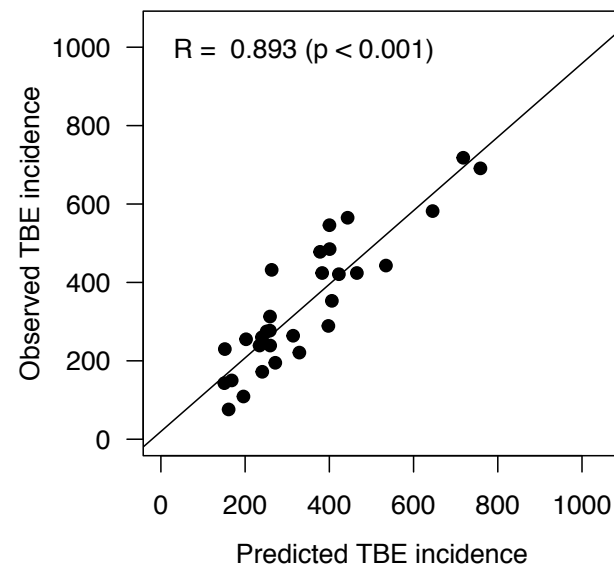
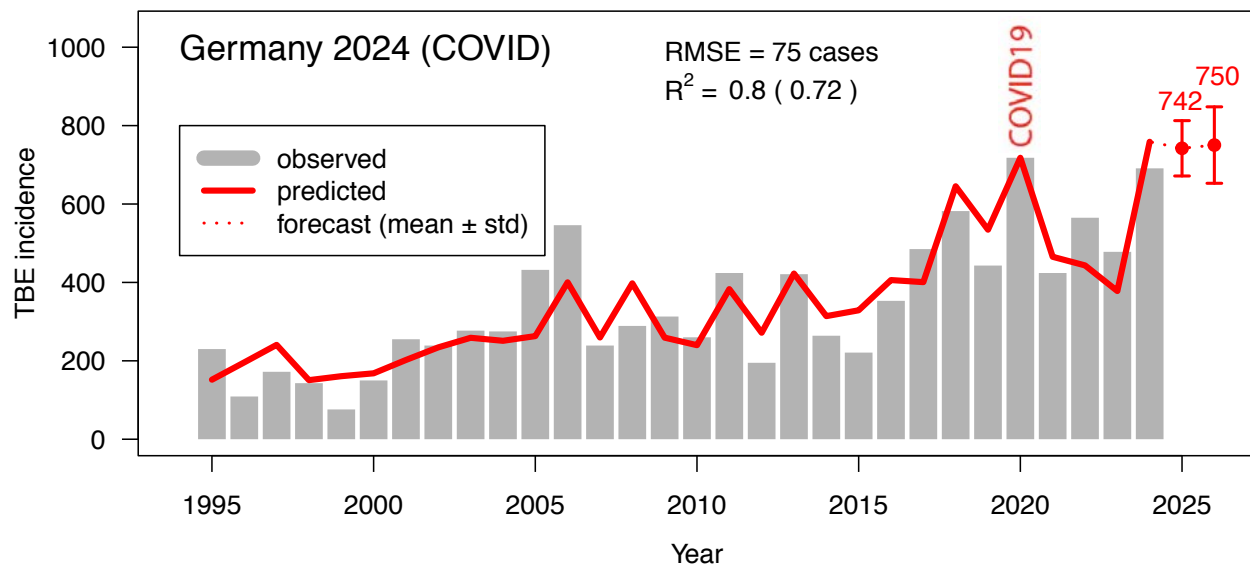
Starting in 2022, the COVID-19 pandemic was explicitly defined as a predictor to improve the model fit. Thus, **the single COVID-19 event is accurately captured and not considered for forecasting.**

Germany: TBE forecast 2023 for the period 2024-2025



Starting in 2022, the COVID-19 pandemic was explicitly defined as a predictor to improve the model fit. Thus, **the single COVID-19 event is accurately captured and not considered for forecasting.**

Germany: TBE forecast 2024 for the period 2025-2026



Starting in 2022, the COVID-19 pandemic was explicitly defined as a predictor to improve the model fit. Thus, **the single COVID-19 event is accurately captured and not considered for forecasting.**

Verification of TBE forecasts for the next season (year+1)

Year	Observed RKI	Forecast + 1 year			Forecast error	
		mean	std	V	bias	rel error
2018	582					
2019	443	417	70	17%	-26	6%
2020	718	661	110	17%	-57	8%
2021	424	409	83	20%	-15	4%
2022	565	628	99	16%	63	11%
2023	478	488	80	16%	10	2%
2024	691	775	130	17%	84	12%
2025		742	71			
2026						

RKI ... Robert Koch-Institute

V ... Coefficient of Variation (percentage error of the mean), $V = \text{std} / \text{mean} \cdot 100$

Verification of TBE forecasts for the next season (year+1)

Year	Observed RKI	Forecast + 1 year			Forecast error	
		mean	std	V	bias	rel error
2018	582					
2019	443	417	70	17%	-26	6%
2020	718	661	110	17%	-57	8%
2021	424	409	83	20%	-15	4%
2022	565	628	99	16%	63	11%
2023	478	488	80	16%	10	2%
2024	691	775	130	17%	84	12%
2025		742	71			
2026						

17% 10 7%
 percentage error bias forecast error
 of the mean

RKI ... Robert Koch-Institute

V ... Coefficient of Variation (percentage error of the mean), $V = \text{std} / \text{mean} \cdot 100$

Verification of TBE forecasts for the season after next (year+2)

Year	Observed RKI	Forecast + 2 years			Forecast error	
		mean	std	V	bias	rel error
2018	582					
2019	443					
2020	718	670	168	25%	-48	7%
2021	424	539	132	24%	115	27%
2022	565	626	183	29%	61	11%
2023	478	382	89	23%	-96	20%
2024	691	728	171	23%	37	5%
2025		793	186			
2026		750	98			

25%
 percentage error
 of the mean

14
 bias

14%
 forecast error

RKI ... Robert Koch-Institute

V ... Coefficient of Variation (percentage error of the mean), $V = \text{std} / \text{mean} \cdot 100$

Verification of TBE forecasts for the season after next (year+2)

Year	Observed RKI	Forecast + 2 years			Forecast error	
		mean	std	V	bias	rel error
2018	582					
2019	443					
2020	718	670	168	25%	-48	7%
2021	424	539	132	24%	115	27%
2022	565	626	183	29%	61	11%
2023	478	382	89	23%	-96	20%
2024	691	728	171	23%	37	5%
2025		793	186			
2026		750	98			

25%

percentage error
of the mean

14

bias

14%

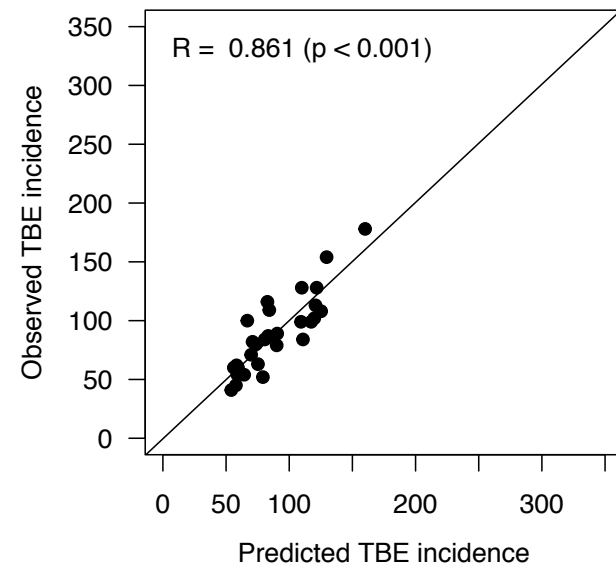
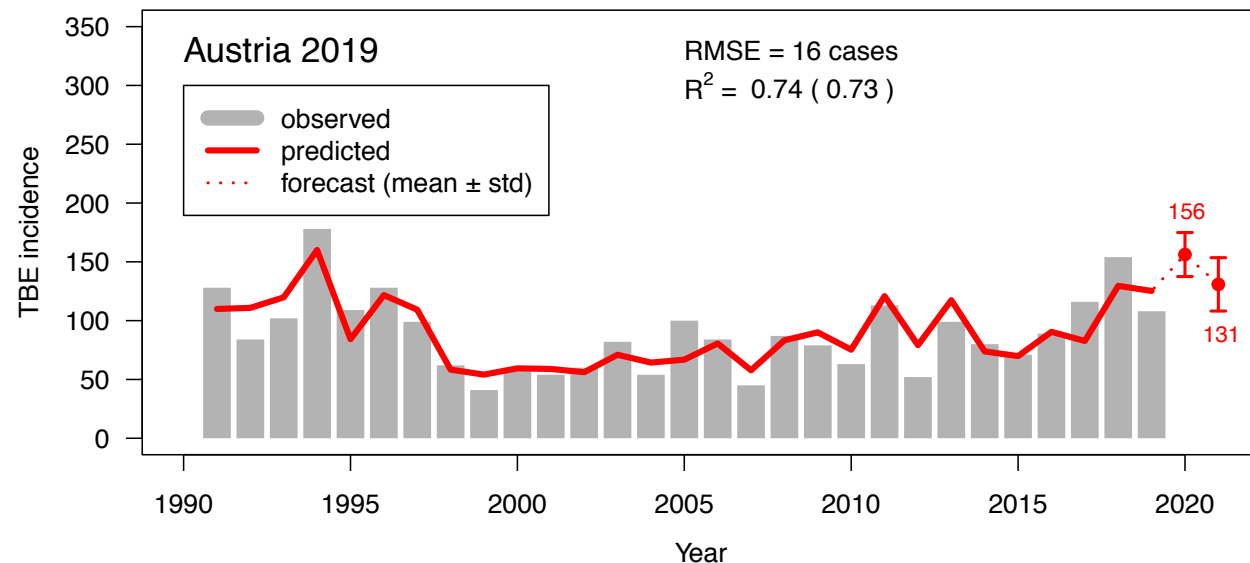
forecast error

Definition of a useful (correct) forecast:

forecast error (%) < error of the mean (%)

Germany: 10(11) Forecasts correct

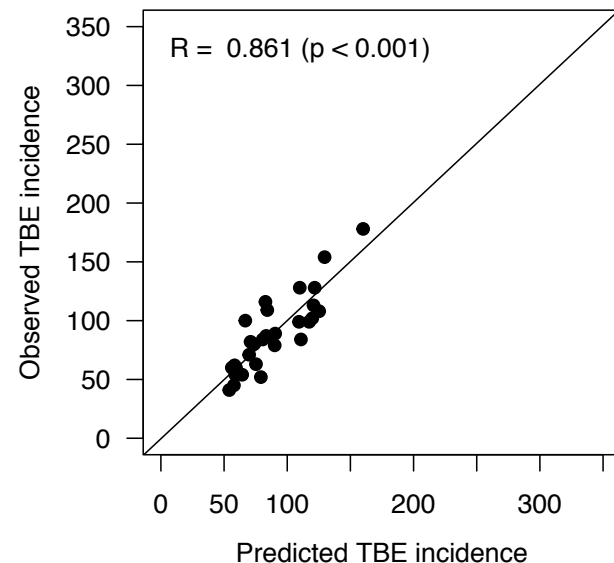
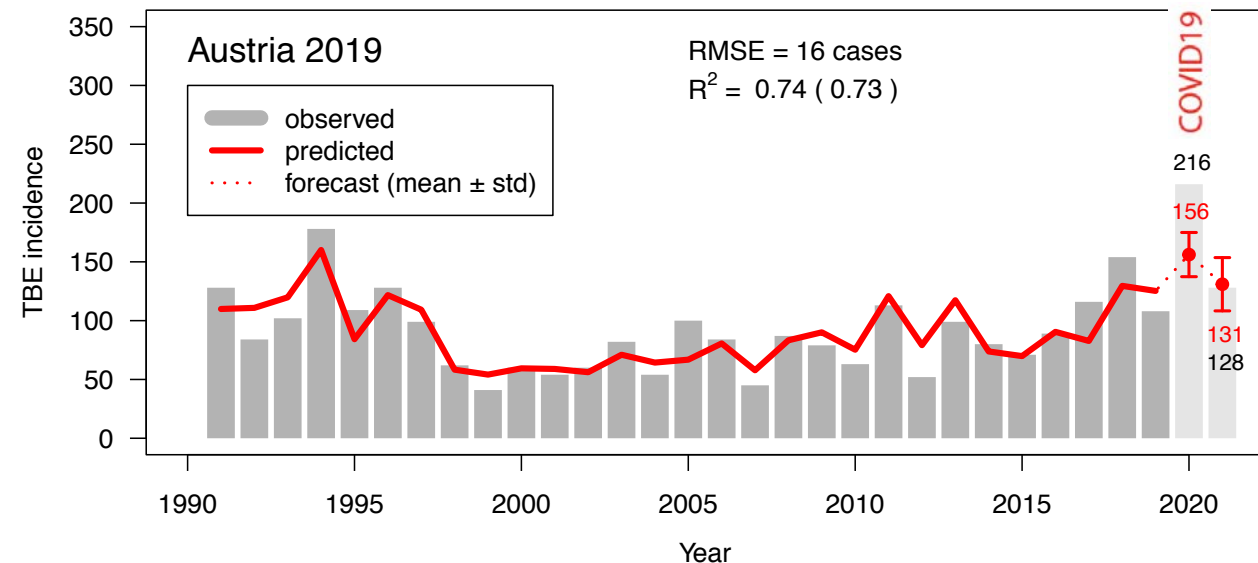
Austria: TBE forecast 2019 for the period 2020-2021



Forecast submitted to TTBD in June 2020 (Rubel and Brugger, 2021)

Rubel, F. and K. Brugger, 2021: Operational TBE incidence forecasts for Austria, Germany, and Switzerland 2019-2021. Ticks Tick Borne Dis., 12, 101579.

Austria: TBE forecast 2019 for the period 2020-2021



Forecast submitted to TTBD in June 2020 (Rubel and Brugger, 2021)

2020: 156 vs. 216 TBE cases (forecast failed due to COVID19)

2021: 131 vs. 128 TBE cases (forecast correct)

Selection of alimentary TBE outbreaks in Europe after 2010

Year	Country	Cases	Reference
2011	Hungary	7	Caini et al. (2012)
2012	Slovenia	3	Hudopisk et al. (2013)
2016	Germany	2	Brockmann et al. (2018)
2016	Slovakia	79	Kerlik et al. (2018)
2017	Slovakia	15	Kerlik et al. (2018)
2017	Germany	8	Robert Koch-Institut (2018)
2020	France	41	Gonzalez et al. (2022)
2023	Slovakia	68	Ličková et al. (2025)



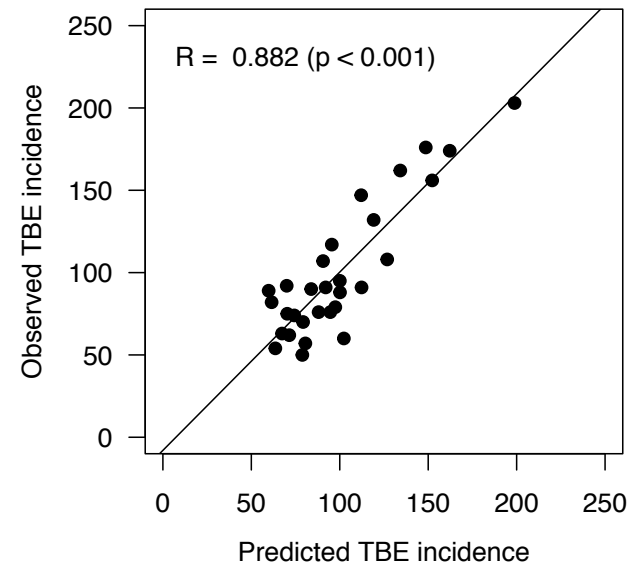
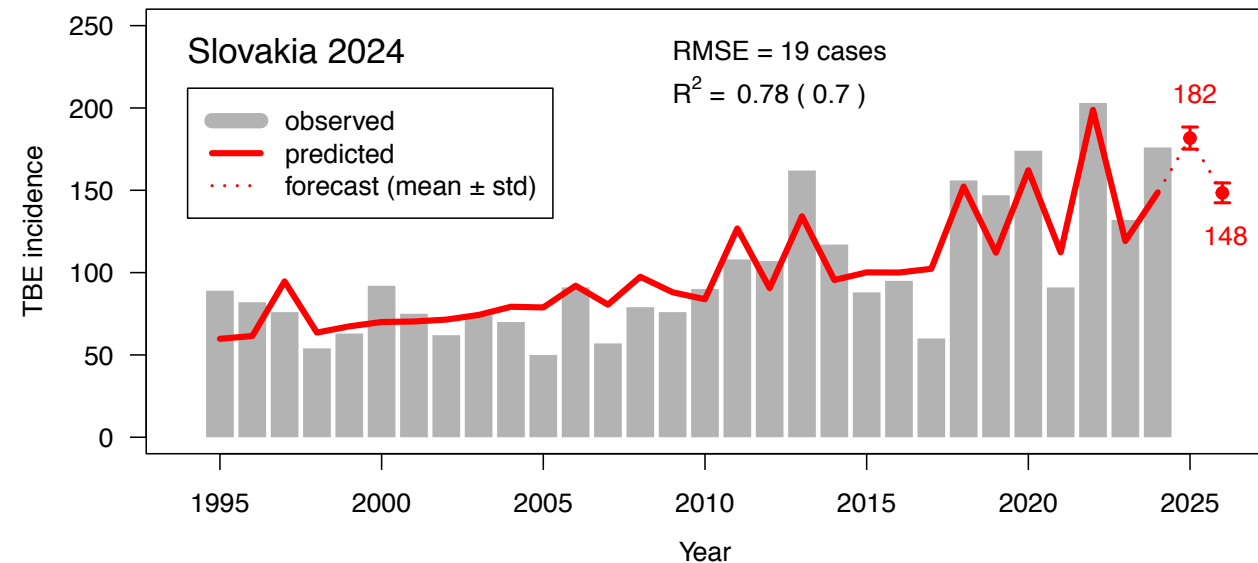
45 %

34 %

TBE cases caused by
consumption of dairy
products (milk, chees)

Food-borne TBE outbreaks are unpredictable and were removed from the Slovak TBE time series before being used for forecasts (additional uncertainty as food-borne cases are often not detected).

Slovakia: TBE forecast 2024 for the period 2025-2026



The TBE model developed for the DACH countries may also be applied to **Slovakia (without food-borne TBE cases)** and other Central European countries.

Lessons from seven years of TBE forecasts

- + Reported annual TBE case numbers are not random.
- + A single beech mast index (here from Bavaria) can be used as a main predictor for the high frequency oscillations of TBE cases in Central European countries.
- + A single atmospheric circulation index (the Scandinavian index provided by NOAA) can be used as a predictor for the low frequency oscillations of TBE cases.
- + Accuracy of the 1-year forecast is 7.1 [2.1 - 11.2] %
2-year forecast is 14.0 [5.4 - 27.1] % (for Germany).
- + Increased TBE incidences during the COVID19 pandemic and caused by food-borne transmission are still be considered as random events.