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THE OCCURRENCE OF SUMMER MASTITIS IN JUTLAND (DENMARK) IN RELATION TO METEOROLOGICAL FACTORS

By

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OLESEN, J. E., S. A. NIELSEN, J. W. HANSEN and P. NANSEN: *The occurrence of summer mastitis in Jutland (Denmark) in relation to meteorological factors.* Acta vet. scand. 1985, *26*, 466—481. — Data for incidence of summer mastitis in 14 veterinary practices in Jutland (Denmark) were related to meteorological factors using statistical methods. A correlation and regression analysis showed that summer mastitis occurred earlier in years with high temperature and precipitation in early summer. The annual number of cases markedly increased over the years 1953 to 1980. This increase was described by applying a linear increase with with year to a logarithmic transformation of the annual incidence.

Analysis of 10-day incidences from the veterinary practices and daily incidence from a test site at St. Vildmose (Jutland) showed that incidence of summer mastitis could be related to temperature and wind velocity within the previous 10 days. High temperature and low wind velocity in this period increase the incidence. This indicates that the incubation period of summer mastitis is at maximum about 10 days. The activity of the fly (Hydrotaea irritans Fall). which acts as mechanical vector for the bacteria is influenced by temperature and wind velocity. This may explain the variation in incidence of summer mastitis during the season and from year to year.

summer mastitis; incidence; insect vector; temperature; wind velocity.

Summer mastitis is an inflammation of one or more quarters of the udder of heifers and dry cows. It is usually caused by a mixture of bacteria of which Corynebacterium pyogenes and Peptococcous indolicus are the most common (*Sørensen* 1979, *Madsen* 1985). Insects are assumed to play an important role for the transmission of the causative bacteria, and the plantation fly, Hydrotaea irritans Fall., has attracted special attention. The involvement of vectors suggests that the disease pattern may be indirectly influenced by climate.

Thus, *Wennemar* (1974), *Popp* (1975) and *Kunze* (1976) found that summer mastitis occurred more frequently in warm and moist summers. Using registrations from 1972 to 74 *Popp* (1975) concluded that only a few hot and humid days could cause a sudden increase in the disease incidence.

The purpose of this investigation was to relate the incidence of summer mastitis to meteorological factors.

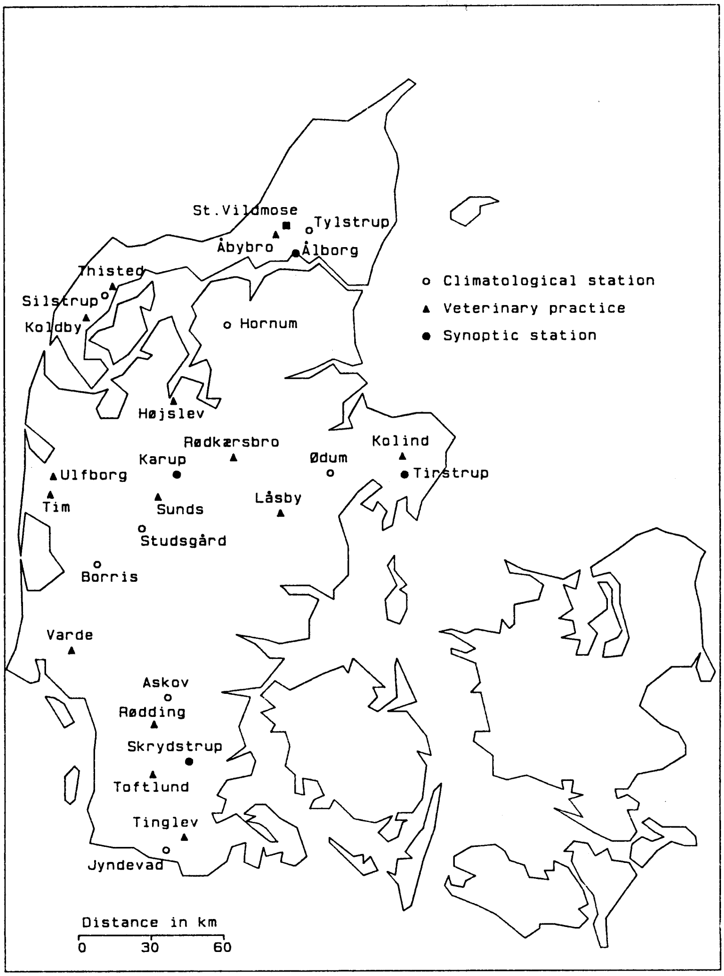
MATERIALS AND METHODS

Observations of summer mastitis

Registrations of the number of treated summer mastitis cases in 14 veterinary practices in Jutland (Denmark) were used in the study. The average number of dairy cows and the average number of summer mastitis cases in the practices are listed in Table 1. Their geographical location are shown in Fig. 1. These practices were selected among others as having the most reliable and complete records. In these practices the same person was in charge of the registrations in all years, and no reorganization of practices occurred.

Table 1. Veterinary practices and corresponding climatological and synoptic stations.

Veterinary practice	Years	Average no. of dairy cows	Average no. of SM cases per year	Climatological station	Synoptic station
Thisted	70—80	4300	44	Silstrup	Aalborg
Koldby	73, 75—80	5500	89	Silstrup	Aalborg
Åbybro	54—80	2500	19	Tylstrup	Aalborg
Højslev	70—80	7000	66	Hornum	Karup
Rødkjærsbro	55—80	3000	26	Ødum	Karup
Kolind	72—80	5100	45	Ødum	Tirstrup
Låsby	75—80	2400	17	Ødum	Tirstrup
Ulfborg	61—74	2000	24	Borris	Karup
Tim	72—80	3600	42	Borris	Karup
Sunds	53—57, 59—70	3000	18	Studsgård	Karup
Varde	75—80	7000	178	Askov	Skrydstrup
Rødding	71—72, 74—80	4700	72	Askov	Skrydstrup
Toftlund	70—80	3600	95	Jyndevad	Skrydstrup
Tinglev	74—80	6300	226	Jyndevad	Skrydstrup



F i g u r e 1. Observation localities in Denmark.

The study only included the number of treated cases and not the the total number of summer mastitis cases in the practices. It is assumed that the relatively small fraction of incidents, which were not treated remained constant throughout the years.

The total daily number of summer mastitis cases in St. Vildmose was registered during the years 1971 to 1981. The geographical location of St. Vildmose is shown in Fig. 1. This material was partly used for comparison and validation purposes and partly for examining the relation between daily incidence and meteorological factors.

Climatic data

The climatic data were recorded at the climatological stations at experimental stations in Jutland (Fig. 1 and Table 1). Monthly and 10-day values of a number of climatic variables were used (Table 2). No registrations of wind velocity were available from these climatological stations.

Table 2. Monthly and 10-day climatic variables.

Symbol	Variable
Climatological stations	
T	Mean temperature, °C
P	Precipitation, mm
PD	Number of days with precipitation
FR	Number of days with frost
Synoptic stations	
V6	Percentage of hours having a wind velocity less than 6 m/s
V8	Percentage of hours having a wind velocity less than 8 m/s

Registrations of wind velocity were taken from 4 synoptic stations (Fig. 1). The wind velocity in 10 m height was recorded each hour or each third hour. Only the registrations from 7 AM to 10 PM were used. The variables calculated from the wind velocity are listed in Table 2.

The symbols for the monthly variables may be supplied with a suffix denoting the number of the month in question, e.g. T6 denotes the mean temperature of June. The symbols for the 10-day variables may have an index denoting the time lag relative to the observation of summer mastitis, e.g. T_1 is the mean temperature of the previous 10-day period.

The registrations from St. Vildmose were related to monthly and 10-day climatic variables monitored in Tylstrup 1971 to 1981 as well as to the daily meteorological variables from the synoptic station at Aalborg monitored during the same period of time. The daily meteorological variables were mean temperature, mean wind velocity, mean relative humidity, precipitation and the number of hours with rain, showers or thunder. All daily variables were calculated using registrations from 7 AM to 10 PM only.

Statistical methods

The relations between the cases of summer mastitis and the climatic variables were examined by means of simple correlation analysis and multiple linear regression models (*Draper & Smith* 1966):

$$y_i = b_0 + b_1 x_{1i} + \ldots + b_k x_{ki} + e_i, i=1, \ldots, n \qquad (1)$$

The dependent variable (y) is assumed to be a linear function of the explanatory variables (x_1, x_2, ..., x_k) plus a residual (e). The stepwise procedure (*Helwig & Council* 1979) was used for selection among the possible explanatory variables.

A cross validation technique was employed for validation of the selected regression models. Using this technique the data are divided into several groups of observations. The parameters are then estimated using (a-1) of the (a) groups of observations, and the predicted values ($\hat{y}$) are calculated for the remaining group. This procedure is carried out for all (a) combinations of groups. The prediction standard deviation (s_{cv}) is then calculated as:

$$s_{cv} = \sqrt{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2 / n} \qquad (2)$$

where n is the total number of observations. s_{cv} is an assessment of the prediction error of the model.

RESULTS

Summer mastitis cases in relation to time

Fig. 2 shows the frequency distribution of the number of cases of summer mastitis in the 10-day periods for all practices. The number of incidents is approximately normally distributed in regard to time. The maximum number of incidents occurred in August.

The time of occurrence of summer mastitis (M_T) each year was here defined as the day number in the year of the median of the incidence distribution with time, i.e. M_T is the day when half the annual number of cases has occurred. As the incidents were calculated on a 10-day basis, M_T expresses the middle day number of the median 10-day period. Only those practices

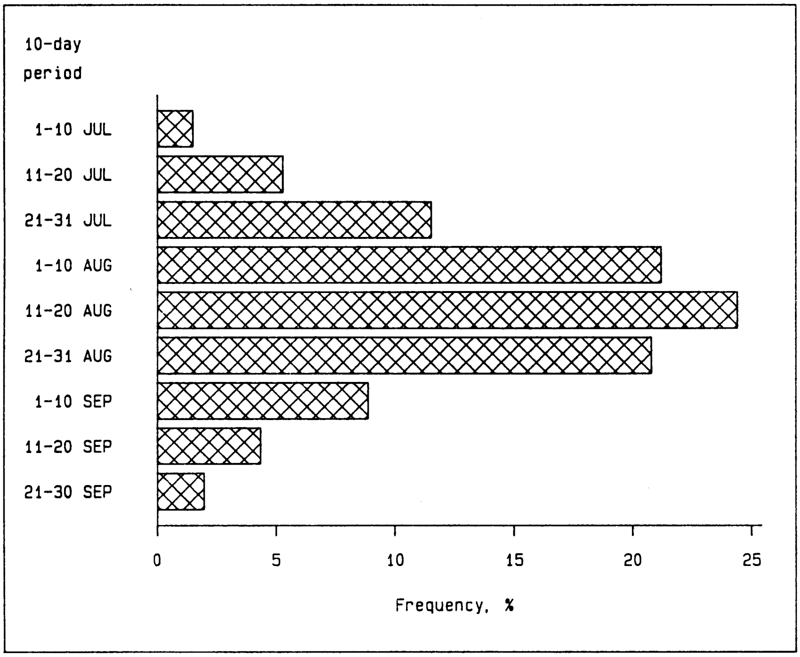


Figure 2. Frequency distribution of number treated cases of summer mastitis in 14 veterinary practices.

and years, where more than 20 cases occurred were used in this analysis.

The correlations between climatic variables and M_T are shown in Table 3. Negative correlations were obtained between M_T and temperature and precipitation in April to July.

Table 3. Correlation coefficients for the median time of summer mastitis (M_T) with climatic variables (Table 2) for the months March to July. 98 observations.

Climatic variable	Month 3	4	5	6	7
T	—0.023	—0.287**	—0.226*	—0.102	—0.242*
P	0.075	0.038	—0.076	—0.211*	—0.197
PD	0.008	—0.038	—0.147	—0.263**	—0.085

Levels of significance: *: $0.01 < P \leq 0.05$
**: $0.001 < P \leq 0.01$, ***: $P \leq 0.001$

The stepwise method was used for selecting regression models with M_T as the dependent variable and the variables in Table 3 as possible explanatory variables. The results of the stepwise procedure are shown in Table 4. The multiple regression coefficient (R^2) and the standard deviation (s_{cv}) from a cross validation are also listed. The cross validation was carried out using year as classification criterion.

Table 4. Selection of regression models for the median time of summer mastitis (M_T) using the stepwise method. The symbols for the climatic variables are described in Table 2. 98 observations.

Explanatory variables	R^2	s_{cv}
T4	0.082	9.22
T4 T7	0.139	9.07
T4 T7 T6	0.197	8.86
T4 T7 T6 PD5	0.227	9.09
T4 T7 T6 PD5 PD6	0.288	8.57
T4 T7 T6 PD5 PD6 T5	0.318	8.44

The following model was selected:

$$M_T = 338.2 - 2.9\ T4 - 2.7\ T5 - 2.4\ T6 - 1.4\ T7 - 0.65\ PD5 - 0.50\ PD6 \qquad (3)$$

The results show that high temperature and a high number of precipitation days in early summer accelerates the development of summer mastitis. A correlation analysis using data from St. Vildmose showed the same features for temperature in May and precipitation in June.

The mean number of incidents in July in percentage of the annual number of incidents is mapped out in Fig. 3. It shows that summer mastitis occurred earlier in southern and central Jutland compared to northern Jutland and the coastal areas. The areas with a high incidence in July coincide with areas having relatively high normal temperatures in May and June (Fig. 3) and a relatively large precipitation in May to July (*Danish Meteorological Institute* 1975).

The annual incidence of summer mastitis

The number of affected animals in percentage of cows during a year is denoted M_Y. Fig. 4 shows that M_Y is increasing rapidly

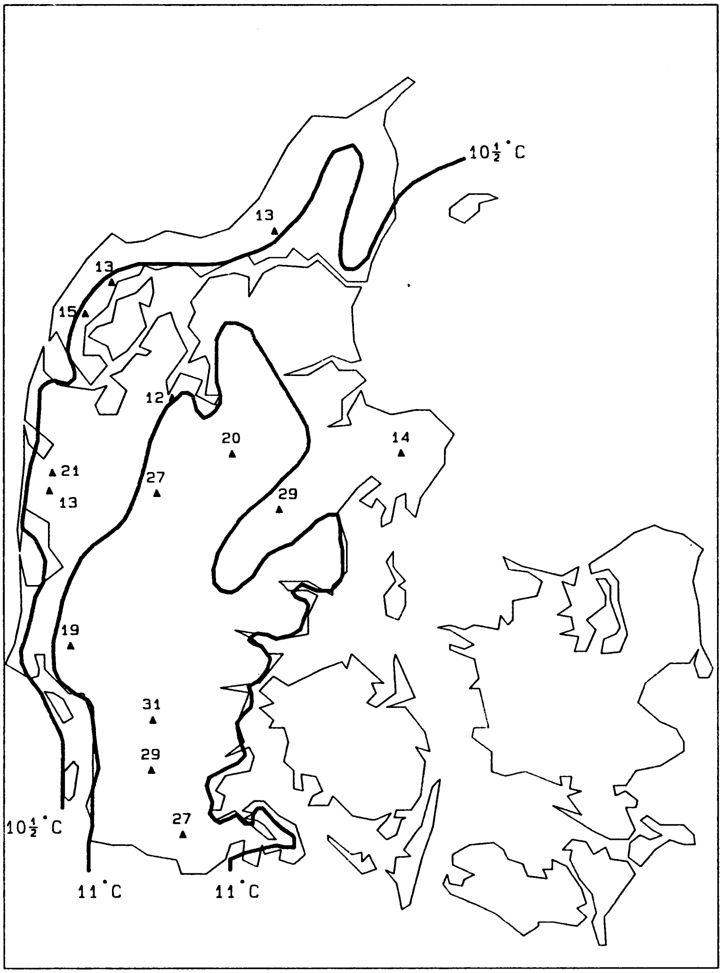
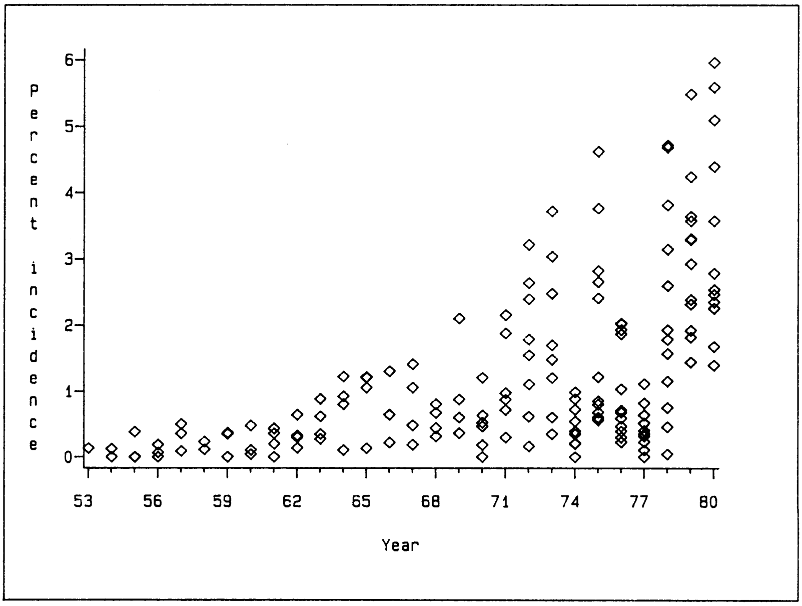


Figure 3. Map of Denmark showing the mean incidence in July in percentage of the annual incidence. Isolines for normal mean temperature in May are also shown (Danish Meteorological Institute 1975).

with year. The variation within the years is also increasing with year. This is due to the number of incidents being a discrete variable with a variation that is increasing as the level of M_y increases. It therefore seems natural to use a logarithmic form of M_y, as this will stabilize the variance (*Rudemo* 1979).

As the number of incidents is zero in some years, the following logarithmic form of M_y was used: ln $(M_y + 1)$, where ln denotes the natural logarithm. Using the logarithmic form of M_y a



F i g u r e 4. Annual incidence of summer mastitis in 14 veterinary practices expressed in percentage of the number of dairy cows.

slightly more stable variance and a more linear dependency on year was obtained. It should be noted ,that using this logarithmic form as the dependent variable in regression analysis causes the effect of the explanatory variables to be multiplicative rather than additive.

The following model explained 54.3 % of the variation in $\ln(M_Y+1)$:

$$\ln(M_Y+1) = b_0 + a_i V_i + b_1 Y \qquad (4)$$

where V_i denotes the veterinary pratice as a class variable and Y is year as a covariate. Both the effect of practice and year were significant at the 0.1 % level (partial F-test). By including $\ln(M_Y+1)$ from the previous year as an additional explanatory variable in model (4) it was shown that the effect of this variable was not significant at the 5 % level. It may thus be assumed that no autocorrelation exists in the annual incidence.

A correlation analysis showed that the residuals from model (4) were positively correlated with mean temperature in November and December of the previous year and negatively correlated with precipitation in January and February. As the residuals were not independent due to high intercorrelation within the years the significance test could not be used here.

10-day incidence of summer mastitis

The number of cases of summer mastitis in a 10-day period in percentage of the number of dairy cows per year and practice is denoted M_t. The following model explained 17.8 % of the variation in ln (M_t+1) for the months July to September:

$$\ln (M_t+1) = b_0 + a_i V_i + b_1 Y \quad (5)$$

The correlations between various climatic variables and the residuals from model (5) are shown in Table 5. In order to account for the annual variation in mean temperature, the deviation (DT) from normal mean temperature was calculated. The normal temperature used was from 1931—60 for Denmark in general. The significance levels in Table 5 should not be trusted in detail, as some intercorrelation exists in the residuals.

Table 5. Correlations between various climatic variables (Table 2) and the residuals from model (5). 1485 observations.

Climatic variable	Time lag (10-days) 0	1	2
T	0.309***	0.343***	0.121***
DT	0.167***	0.148***	—0.100***
P	0.065*	0.025	0.042
PD	—0.003	—0.016	0.047
V6	0.108***	0.150***	0.018
V8	0.122***	0.154***	0.055*

Levels of significance: *: $0.01 < P \leq 0.05$
**: $0.001 < P \leq 0.01$, ***: $P \leq 0.001$

The stepwise procedure was used for selecting regression models for ln (M_t+1) (Table 6). The following variables were used as possible explanatory variables: Y, DT_0, DT_1, P_0, P_1, PD_0, PD_1, $V6_0$, $V6_1$, $V8_0$, $V8_1$. In order to eliminate the effect of veterinary practice ln $(M_Y+1)—a_i V_i$ was used as dependent variable in the stepwise procedure.

Table 6 shows the result of the stepwise procedure. The standard deviation from cross validation (s_{cv}) decreased only slowly

Table 6. Selection of regression models for the 10-day incidence of summer mastitis ($\ln (M_t+1)$) using the stepwise method. The symbols for the climatic variables are described in Table 2. 1485 observations.

Explanatory variables	R^2	s_{cv}
Y	0.178	0.166
Y DT_0	0.201	0.164
Y DT_0 $V8_1$	0.217	0.163
Y DT_0 $V8_1$ P_0	0.226	0.163
Y DT_0 $V8_1$ P_0 $V8_0$	0.230	0.162
Y DT_0 $V8_1$ P_0 $V8_0$ DT_1	0.230	0.162
Y DT_0 $V8_1$ P_0 $V8_0$ DT_1 PD_1	0.236	0.163

at the inclusion of explanatory varibles. A minimum s_{cv} was obtained with the model including 6 explanatory variables. This model was estimated as:

$$\ln (M_t+1) = b_0 + a_i V_i + 0.0095 \; Y + 0.012 \; DT_0 + 0.006 \; DT_1 + 0.0011 \; V8_0 + 0.0012 \; V8_1 + 0.0009 \; P_0 \qquad (6)$$

The parameter estimates for all variables except DT_1 were significant at the 0.1 % level. A correlation analysis using data from St. Vildmose showed the same features as Table 5. It may thus be concluded that high temperatures, low wind velocities and moist conditions within the previous 2 weeks increase the incidence of summer mastitis. The temperature at time lag 2 (3 to 4 weeks) seems, however, to exert a negative influence on the number of incidents.

Daily values from St. Vildmose

The incidence of summer mastitis was recorded daily in the St. Vildmose area during the years 1971 to 1981. In order to smooth the data and to eliminate the effect of higher number of registered incidents on Mondays, a 3-day running mean was applied to the data. The daily number of incidents from the 3-day running mean is denoted M_d.

No marked change in the population of heifers occurred over the years in this area, and the increase in incidence with year is not quite as pronounced here as for the veterinary practices. The data will therefore not be corrected for herd size or effect of year. Only the observations from 1971 to 1980 and from the first registration in July to the last registration in September have been used.

In order to eliminate the effect of the annual variation in temperature and relative humidity the deviation from the normal variation in these variables were used. The annual variation in wind velocity and precipitation was not considered large enough to be important.

A correlation analysis between ln (M_d+1) and the meteorological variables at different time lags showed that temperature and wind velocity were the most important meteorological variables. The following model was applied at different time lags:

$$\ln (M_d+1) = b_0 + b_1\, DT_i + b_2\, W_i \qquad (7)$$

where DT_i and W_i are daily values of mean temperature deviation from normal and wind velocity at time lag (i). Fig. 5 shows the parameter estimates at different time lags. The parameter

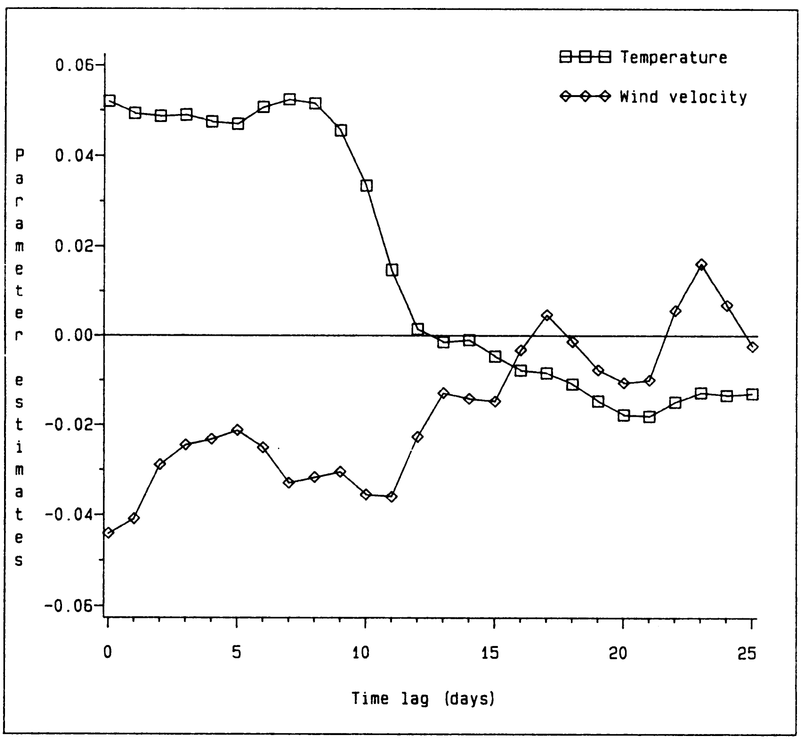


Figure 5. Parameter estimates for model (7) at different time lags.

estimates were positive for temperature and negative for wind velocity at time lags up to 10 days. At greater time lags the parameter estimates for wind velocity are approximately zero and slightly negative for temperature deviation.

The inclusion of relative humidity and precipitation in model (7) showed a small positive effect of relative humidity at time lags of 5 to 10 days and no effect of precipitation amount was observed.

The period from 0 to 10 days in time lag was selected for closer examination. The mean temperature deviation from normal and the mean wind velocity for this period is denoted DT_m and W_m respectively. The number of hours with thunder in this period is denoted TH_m. The following model explained 15.9 % of the variation in ln (M_d+1) (731 observations):

$$\ln (M_d+1) = 1.07 + 0.086\ DT_m - 0.106\ W_m + 0.024\ TH_m \quad (8)$$

Replacing DT_m with mean temperature (T_m) for the period from 0 to 10 days in time lag gave the following model explaining 25.0 % of the variation in ln (M_d+1):

$$\ln (M_d+1) = -0.81 + 0.110\ T_m - 0.072\ W_m + 0.018\ TH_m \quad (9)$$

The parameter estimates for all variables in models (8) and (9) were significant at the 0.1 % level. No significant effect of any other variables including the number of hours with rain or showers were found.

Model (8) and (9) shows that high temperature, low wind velocity and occurrence of thunder within the previous 10 days increases the incidence of summer mastitis. Model (9) explains a larger part of the variation in ln (M_d+1) than model (8) because model (9) includes the annual variation in temperature, which to some extent coincides with the annual variation in incidence of summer mastitis.

DISCUSSION

A correlation and regression analysis showed that summer mastitis occurs earlier in years with high temperature and precipitation in early summer. Temperature in particular seems to be important. A high temperature in early summer probably advances the development of fly species acting as vectors for the disease.

Fig. 3 shows that summer mastitis occurs earlier in the southern and central part of Jutland. In this region the temperature and precipitation in early summer is relatively high. Areas with high temperature and areas with a large precipitation in early summer are practically identical which makes it difficult to separate the effect of these two variables. This identity of areas may contribute to the selection of precipitation as an explanatory variable in model (3).

Fig. 4 shows that incidence of summer mastitis is rapidly increasing through years. Using a logarithmic transformation an almost linear increase with year was obtained. The effect of year and location was able to explain more than 50 % of the variation in annual incidence. The rapid increase in incidence through years cannot be explained by climatic changes.

Analysis of 10-day incidence from the veterinary practices and daily incidence from St. Vildmose showed that the incidence of summer mastitis primarily depends on temperature and wind velocity within the previous 10 days. High temperature and low wind velocity in this period increases the incidence. Thunder in this period may also increase incidence. This is probably due to changes in temperature and air humidity during thunderstorms.

In general there is a good agreement between the relations obtained for the veterinary practices and those obtained from analysing data from the St. Vildmose area. Model (6) shows a small positive effect of precipitation on the 10-day incidence from the veterinary practices. At St. Vildmose a small positive effect of relative humidity rather than precipitation was observed. The effect of precipitation on the 10-day incidence is probably indirect, as precipitation generally is associated with an increase in relative humidity.

The effect of temperature on incidence corresponds with results by *Wennemar* (1974) and *Kunze* (1976). This is probably caused by a higher activity of the flies in warm weather (*Nielsen et al.* 1972).

Table 5 and Fig. 5 show a negative correlation between incidence and the temperature deviation from normal at a time lag of 2 to 3 weeks. A corresponding negative correlation between wind velocity and incidence was not obtained at this time lag. This indicates that a cold period followed by a warm period may cause a particular high incidence.

Assuming that the meteorological factors influence the outbreak of summer mastitis Fig. 5 shows that the incubation time for summer mastitis is at maximum about 10 days.

The statistical relations between summer mastitis and meteorological factors described here are not suited to provide the sole basis for a warning service against summer mastitis. The statistical analysis shows, however, that meteorological factors play an important role in determining the occurrence of summer mastitis.

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SAMMENDRAG

Forekomsten af sommermastitis i Jylland (Danmark) i relation til meteorologiske faktorer.

Data for incidensen af sommermastitis i 14 veterinære praksis-områder i Jylland (Danmark) sammenholdtes med meteorologiske faktorer ved anvendelse af statistiske metoder. En korrelations- og regressionsanalyse viste, at sommermastitis forekommer tidligere i år med høj temperatur og nedbør i forsommeren. Den årlige incidens stiger stærkt op gennem årene fra 1953 til 1980. Denne stigning kunne beskrives som en lineær stigning i en logaritmisk form af den årlige incidens.

Analyse of 10-døgns incidensen fra de veterinære praksis-områder og af den daglige incidens fra et forsøgsområde i St. Vildmose (Jylland) viste, at incidensen af sommermastitis afhænger af temperatur og vindhastighed i de foregående 10 dage. Høj temperatur og lav vindhastighed i denne periode forårsager en stigning i incidensen. Dette indikerer, at inkubationstiden for sommermastitis maksimalt er ca. 10 døgn. Temperatur og vindhastighed påvirker formentlig aktiviteten af de insekter, der virker som vektorer for sygdommen, med deraf følgende påvirkning af den kliniske sygdoms incidens.

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