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Computer simulation of the role of the face fly, Musca autumnalis, in spreading and causing infectious bovine keratoconjunctivitis (IBK), based on field data

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ABSTRACT. Face fly counts were made in three lowland pastures of Hungary on the whole body and on the eyes of cattle and also the duration of face fly visits on eyes were measured. As a mean, 13.6 face flies per body and 2.63 face flies per head were found with 21.9% of flies on the eyes. Half of the face fly visits is of short duration (less than 10 seconds) but one-third of the visits is longer than one minute. Flies of this latter category may be involved in causing mechanical damage to bovine eyes. A stochastic computer simulation was made modeling the pasture situation with host changes, based on our field data. Simulation results suggest that the activity of face flies can alone maintain complete infestation in a herd by their host changes with infective agents. The most important simulation result is that long (>60 seconds) fly visits (i.e. mechanical damage to eyes) with evening mean values may have extremely high individual values.

KEY WORDS: Diptera, face fly, Musca autumnalis, IBK, transmission, computer simulation.

Infectious bovine keratoconjunctivitis (IBK, pinkeye, keratitis contagiosa, New Forest disease, infectious ophthalmia, infectious keratitis etc.) occurs wherever cattle are present. A vast amount of papers including reviews are available in the world literature; here we mention an excellent and rather recent review of PUNCH and SLATTER (1984), who summarized the relevant literature on its prevalence and economic importance, etiology, clinical signs, predisposing factors (incl. face flies), pathology and immunology and the current treatment regimes. As they say, IBK has been regarded as a syndrome rather than a specific disease. Various bacteria and mycoplasmas, rickettsiae, viruses and nematode parasite species of the genus Thelazia had been reported as etiological agents but they conclude (see also HALL, 1984) that Moraxella bovis Hauduroy is the true etiological agent. In the same year HALL (1984) published a concise review on the relationships of the face fly, Musca autumnalis

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De Geer, to pinkeye in cattle, where not only a summary but a critical evaluation of the relevant literature was given stating that the data available fulfil the criteria (similar to KOCH's postulates) necessary to incriminate the face fly as a vector of Moraxella. MORGAN et al. (1983) published an annotated bibliography of the face fly with 837 citations of papers, books etc.: this is though not a complete bibliography but undoubtedly includes all the important papers on this species till 1982. Many excellent papers and reviews on the biology and control of M. autumnalis are available, the latest one is that of PICKENS and MILLER's (1980). A more detailed information on the relevant literature is available also in the bibliographies of the above papers. Here only some more papers are mentioned. GERHARDT et al. (1982) demonstrated a definite decrease of IBK cases after a fly control. PAPP and GARZÓ (1985) published numerous new data of flies of pasturing cattle in Hungary, including a simultaneous evaluation of the activity of the larval and imago populations of the face fly. There an estimation is also given for the determination of the ratio of the imaginal population which is on the bodies of cattle at a moment: this value is only 0.1 to less than 1.0% (probably about 0.5%). This datum is a tool for a better evaluation of the findings of BERKEBILE et al.(1981), who found that less than 1% of the imagoes were contaminated in a herd in IBK. ARENDS et al. (1982, 1984) reported on convincingly successful trials on laboratory and field transmission of Moraxella bovis to cattle by face flies. GLASS and GERHARDT (1983, 1984) demonstrated the way of transmission of M. bovis, analysing the relationships of feeding activity of face flies and revealing the transmission of vast amounts of bacteria by regurgitation from the crop. GLASS et al. (1982) stated that M. bovis can survive one day only in the alimentary tract but about three days on the body. BROWN and ADKINS (1972) studied the feeding activity of face flies in order to determine the relative contribution of mechanical "irritation" and bacterial infection to the production of IBK; they found that also calves kept uncontaminated were indicative of mild to moderate pinkeye through irritation by the mouthparts of face flies. SHUGART et al. (1979) were among the first ones who demonstrated the ability of face flies to cause direct damage to the eyes of cattle. They proposed an economic injury level of one face fly/eye/month). BROCE and ELZINGA (1984) and KOVÁCS-SZ. (1987) demonstrated that morphological characteristics of prestomal teeth and of some other mouthparts of the face fly account for the observed damage caused to the eyes of cattle. There are rather numerous papers also on fly counts (incl. face fly) on the body of cattle, e.g. HILLERTON et al. (1984) published results of fly counts on five species (incl. M. autumnalis) associated with dairy heifers in southern England (from the back, belly, teats and head) in order to judge the species involved in the transmission of summer mastitis by their site preference. However, no data have been found on the absolute number of face flies visiting cattle eyes and on the ratio of their numbers on the whole body and on the eyes. In order to collect data on the possible elements of activity of face flies on the eyes of cattle, it was essential to collect data also on the duration of their visits on eyes.

FIELD DATA

Face fly counts[x] were made in three lowland pastures in East and Central Hungary: Füzesgyarmat, Holstein-Friesian heifers in various stages of pregnancy, mild pinkeye in some

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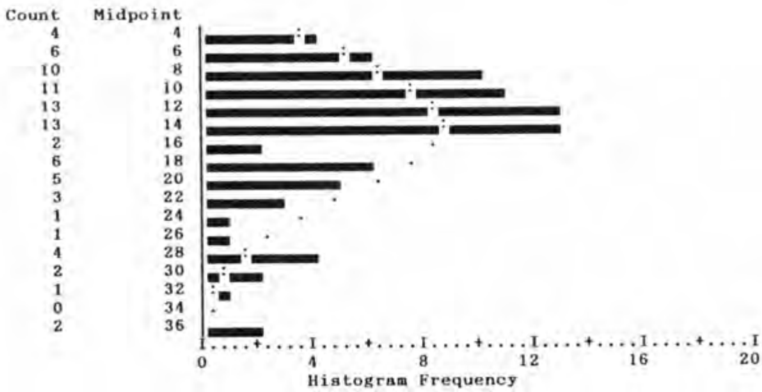
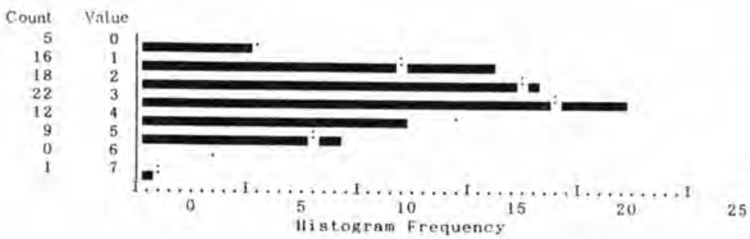
[x]Face flies (Musca autumnalis De Geer, 1776) are easily differentiable from the smaller bodied flies of Haematobia and Hydrotaea, Musca osiris and M. tempestiva; the stable fly (Stomoxys calcitrans L.) is very much other shaped, the housefly, Musca domestica L., does not occur in pastures. The only other species in Hungary, which is so similar to the face fly that one cannot differentiate it by this method, is Musca larvipara; however, the populations of this latter species are only ca. 0.1-0.2% of those of the face fly in lowlands of Hungary.

Diagram 1. Number of face flies counted on cattle (total fly numbers in 83 counts)



(mean 13.590; std err. 0.793; median 12.0; mode 13.0; std dev. 7.225; variance 52.196; kurtosis 0.824; S E kurt. 0.523; skewness 1.049; S E skew. 0.264; range 34.0; minimum 3.0; maximum 36.0; sum 1128.0)

Diagram 2. Number of face flies on eyes (83 counts)



(mean 2.627; std err. 0.162; median 3.0; mode 3.0; std dev. 1.479; variance 2.188; kurtosis 0.243; S E kurt. 0.523; skewness 0.279; S E skew. 0.264; range 7.0; minimum 0.0; maximum 7.0; sum 218.0) animals; Ócsa, Holstein-Friesian x Hungarian Fleckvieh x Jersey crossbreds, dairy cows (5 to 7 years old), no IBK; Apajpuszta, Hungarian Fleckvieh and crossbred cows and heifers) in August of 1985 and 1987. Body and eye counts were made by a TASCO 10 x 50 binoculars. Altogether 83 pairs of data were collected, on at least 20 animals per locality. Since the results from the three localities do not differ significantly, all the data were combined and processed together.

The duration of face fly visits on the eyes of cattle was observed through the binoculars and clocked by a Hanimex stop-watch. Timing was made in an independent series of observations (160 data) but possibly on the same animals which were involved in fly counts. Another two cows (Apajpuszta, Sept. 15, 1985, Hungarian Fleckvieh) suffering from IBK were also observed (fly counts and timing) but these data were not used later (but in one respect only, see below).

Our field data are summarized in Diagrams 1-4.

As it appears from these data, on the average 13.6 face flies per body and 2.63 face flies per head were found with 21.9% of flies on the eyes (the most frequent values /modes/ are 13.3 , and 23.077, respectively). Diagram 4 on the duration of fly visits on eyes shows an unusual form: this histogram is - in all probability - a summation of several behavioral elements of different length of time (simple sucking and food uptake after causing microlesions by their mouthparts, cf. KOVÁCS-SZ. 1987, are suspected). Half of the face fly visits is short in duration, i.e. less than 10 seconds but one-third of the visits (56 of the total of 160) is longer than one minute. The long-staying visitors can very likely use their prestomal teeth causing mechanical damage to the conjunctive and to other parts of bovine eyes.

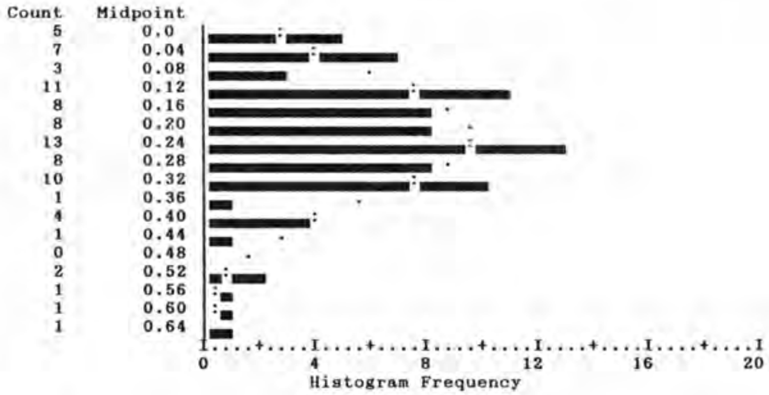
SIMULATION AND MODEL PARAMETERS

We decided to link the elements of knowledge on the role of Musca autumnalis in transmitting and causing infectious bovine keratoconjunctivitis by constructing a computer simulation model. In this study our field data and some data of the literature were used. Since we believe that the role of face flies in contamination is mainly connected with their moving, we should have operated with matrices including their transition probabilities. The only problem is that the collection of observational data enough to construct such matrices may be said to be an almost impossible task. One fly may stay (i) on infectible parts (eye, nose, urogenital parts) of the body of cattle, (ii) on other parts of the body, (iii) on excrements of cattle, (iv) somewhere else in the pasture. Data sufficient for estimating the pairwise transition probabilities could be hardly gained without very large efforts so this way of work had to be given up. When constructing our model we had to canalize our effort on the eye because this is the most important part of body in IBK.

As we have seen earlier, the modus (5 seconds) of measures on time spent on the eye would be misleading.

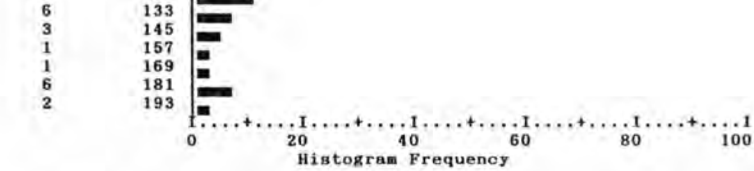
The flies were arbitrarily grouped into three categories. The members of the first group stay for a very short time (1-9.9 seconds). Possibly this time is not enough for the flies to hurt the eye with their mouthparts, but they possibly transmit the bacteria. Flies in the second group spend 10 to 59.9 seconds on the eye. The members of the third group spend more than one minute on the eye and they can be suspected of causing mechanical damage to the eye.

Diagram 3. Ratio of face flies counted on eyes
(eye count/total count)



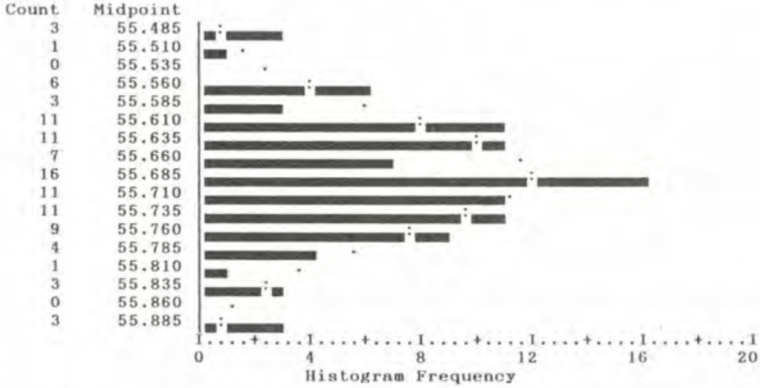
(mean 0.220; Std Err 0.015; Median 0.218; Mode 0.231; Std Dev. 0.138; Variance 0.019; Kurtosis 0.693; S E Kurt 0.520; Skewness 0.723; S E Skew 0.263; Range 0.636; Minimum 0.0; Maximum 0.636; Sum 18.470)

Diagram 4. Duration of face fly visits on eyes (seconds)



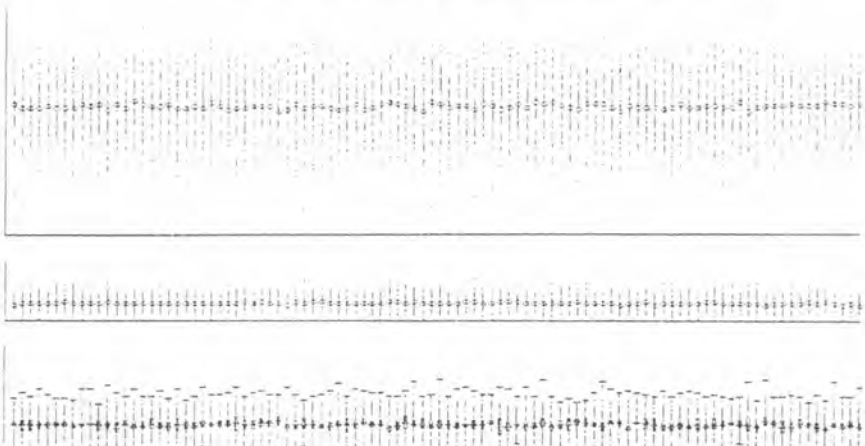
(mean 42.478; std err. 4.429; median 6.850; mode 5.000; std dev. 56.023; variance 3138.585; kurtosis 0.201; S E kurt. 0.381; skewness 1.216; S E skew. 0.192; range 192.0; minimum 1.0; maximum 193.0; sum 6796.45)

Diagram 5. Computer simulation results: number of "host changes" on 20 cattle per hour (one host change = one flying up and one settling); a summary of 100 independent simulations



(mean 55.683; Std err 0.008; median 55.682; mode 55.676; Std dev 0.084; variance 0.007; kurtosis 0.203; S E kurt 0.478; skewness 0.054; S E skew 0.241; range 0.414; minimum 55.478; maximum 55.892; sum 5568.265)

Diagram 6. Computer simulation results: number of face fly visits (mean and range on the eyes of cattle/visit/head/hour)



Successive independent simulations (1st to 100th)
Upper row: short visits (- 9.9 seconds); middle row: medium long visits (10 seconds-59.9 seconds); lower row: long stay visits (over 60 seconds). Each point refers to one discrete situation of a fly visit in the herd of 20 cattle.

The basic rules of simulation were the following. (i) Only flies staying on the cattle were considered. Only this active minority (almost exclusively females) collecting the females in a certain stage of their ovarial cycle is important from our point of view. The largest part (99-99.5%) of the population was handled as a black box called "pasture compartment" (see PAPP and GARZÓ 1985). (ii) The flies included in the simulation move randomly and they do not make any difference between the cows. If a fly had already foraged it is contaminated with bacteria. (iii) The duration of staying on the eye is also random. (iv) If a fly succeeded to stay on the eye a long time (more than one minute) for four times, then it exits from the active minority into the "pasture compartment". This quitting specimen is replaced with an other non-contaminated one from the pasture compartment. This stipulation decreases the transitional ability, but its reality can be justified with observations. Namely, this fly possibly had sucked up enough protein to make its eggs ripen so it leaves the cow. On the body of the fly Moraxella bovis is viable for 3 days. At a constant 30°C temperature the ovarial cycle of the fly takes three days. In Hungary, even on the hottest days the ovarial cycle takes at least 5 days. Thus, when the fly returns to the cattle, the bacteria taken up previously are not alive. (v) If a fly leaves a cow, its probability to return to the same cow is ten times higher than that of its landing on another cow. We have no concrete observations confirming this idea (we plan to measure this probability). We keeo much lower values to be true, but we consciously overestimated this probability in order to reduce the number of changing hosts in the simulation.

The frequency of host change, flies occurring on the eye of cows were the target variables of our simulation model. The simulation was done on an IBM AT compatible computer, with Monte Carlo stochastic simulation. The program was written in TURBO PASCAL language. Since large amounts of random number were generated, and this is a time-consuming process, 20 cows were considered in our program. According to the field data, about 13 flies per cow were counted. The simulation being stochastic, this number naturally fluctuated under the simulation. One running of the program simulated 12 hours (in Hungary, M. autumnalis imagoes are active for a longer time in summer). The program was run 100 times.

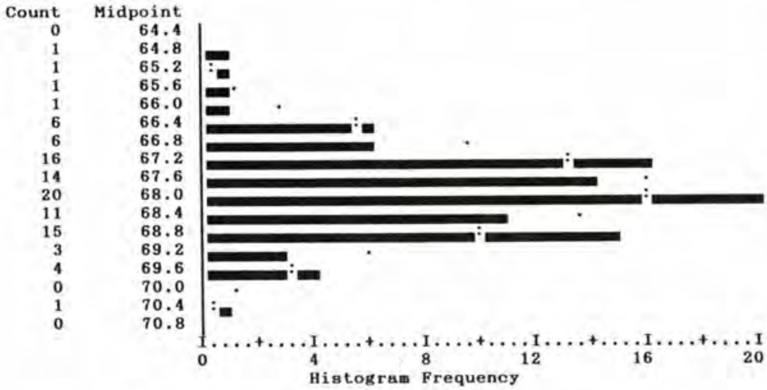
COMPUTER SIMULATION RESULTS

The results are summarized in diagrams 5-10.

According to the simulation results, about three host changes per cow per hour can be counted (Diagram 5: mean 55.683 per 20 cows). The most frequent short stay (less than 10 seconds) was 68 flies per cow per hour. The most frequent middle stay (from 10 seconds to 59.9 seconds) was 8-9 flies per cow per hour. 35 flies per cow occurred for more than one minute. Since counting averages may omit individual differences, the number of long stay visits (Diagram 10) were examined more thoroughly. As one can see, these data have very large standard deviation. During the simulation there occurred a cow with 112 long stay visit (see more below).

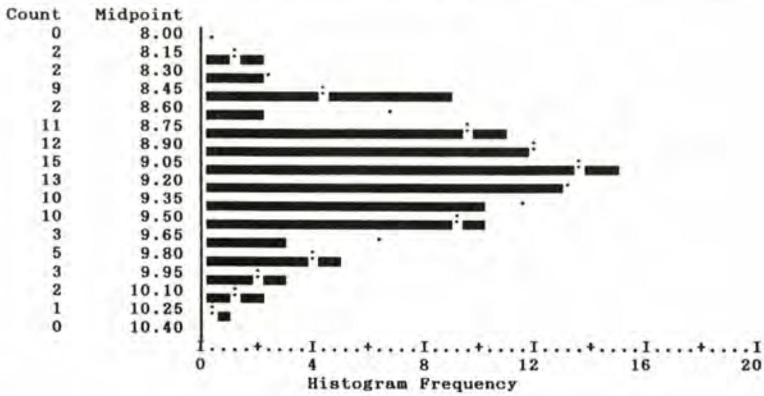
From the simulation results we can infer that in summer on Hungarian lowland pastures only the activity of M. autumnalis imagoes is enough to keep the infection on each animal in a herd if there were animals contaminated with the infectious agent (for example Moraxella bovis). We have to say that the simulated fly densities were far under the Hungarian maximum (cf. PAPP and GARZÓ, 1985) and the model parameters were mainly underestimated. The simulation results suggest that, in the presence of other predisposing factors, the role of populations of M. autumnalis imagoes in causing IBK is a kind of the last drop into the cup to overflow.

Diagram 7. Computer simulation results: the mean number of short fly visits (shorter than 10 seconds) per head per hour (each "count" refers to one independent simulation)



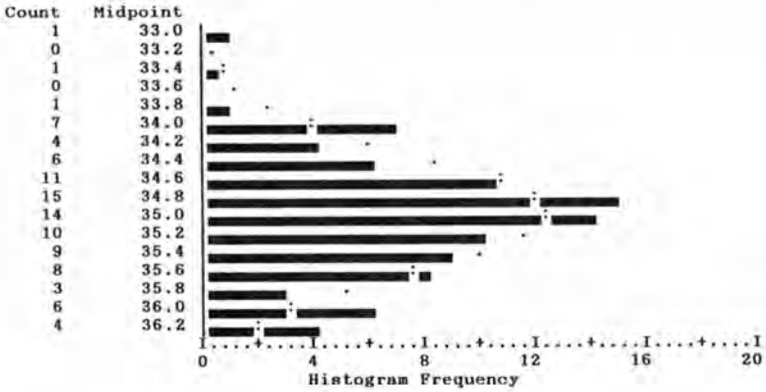
(mean 67.814; std err. 0.098; median 67.900; mode 68.140; std dev. 0.978; variance of 0.956; kurtosis 0.695; S E kurt. 0.478; skewness -0.354, S E skew. 0.241; range 5.700; minimum 64.760; maximum 70.460; sum 6781.380)

Diagram 8. Computer simulation results: the mean number of the medium long fly visits (10 seconds - 59.9 seconds) per head per hour (each "count" refers to one independent simulation)



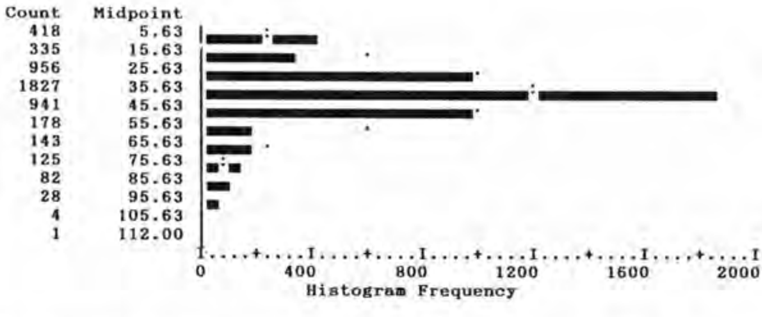
(mean 9.109; std err. 0.044; median 9.090; mode 8.740; std dev. 0.440; variance 0.194; kurtosis -0.225; S E kurt. 0.478; skewness 0.203; S E skew. 0.241; range 2.000; minimum 8.200; maximum 10.200; sum 910.880)

Diagram 9. Computer simulation results: the mean number of long face fly visits (longer than 60 seconds) per head per hour (each "count" refers to one independent simulation)



(mean 34.967; std err. 0.064; median 34.950; mode 35.140; std dev. 0.636; variance 0.405; kurtosis 0.219; S E kurt. 0.478; skewness -0.249; S E skew. 0.241; range 3.320; minimum 32.960; maximum 36.280; sum 3496.680)

Diagram 10. Computer simulation results: number of long (longer than 60 seconds) face fly visits per head per hour (a summary of 100 successive independent simulations)



(mean 35.421; std. err. 0.233; median 35.000; mode 34.000; std dev. 16.539; variance 273.537; kurtosis 1.819; S E kurt. 0.069; skewness 0.794; S E skew 0.034; range 111.373; minimum 0.627; maximum 112.000; sum 178449.569)

The results of this simulation give convincing explanation for the previously unexplainable phenomenon that in a given herd the expressivity of sickness of two eyes of the same cow was observed to be highly independent of each other. It is obvious that any or all of the predisposing factors (UV light, breed, vitamin A deficiency, infective agents, dust, tall grass etc.) affect both eyes at the same rate. However, if one eye suffers - by chance - a higher than average number of face fly bites (we are convinced that the number of bites is proportional to the number of long stay visits) for a couple of days, this will result - like an avalanche - in an increase of lacrimation which provokes more and more long stay fly visits and bites. (On the eyes of the observed ill animals the mean staying time was 105 seconds and 30.6 percent of the flies were on the eyes).

LŐRINCZ G., PAPP L. és KOZMA J.: A Musca autumnalis légyfaj fertőző kötő- és szaruhártya-gyulladással kapcsolatos szerepének számítógépes szimulációja terepadatok alapján

A szerzők három hazai alföldi legelőn számlálták a Musca autumnalis imágókat szarvasmarhák testén és szemén, illetve megmérték azokat az időtartamokat, amelyet a legyek a szemen töltenek. Átlagosan 13,6 légy volt a szarvasmarhák egész testén és átlagosan 2,63 légy a szemen, a kettő arányának átlaga 21,9%-nak adódott. A legyek szemekre szállása az esetek felében igen rövid, 10 másodpercnél rövidebb időtartamú volt. A leszállások egyharmadában a szemen való tartózkodás több mint 1 percig tartott. Ezek a legyek elég hosszú ideig tartózkodnak a szarvasmarhák szemén ahhoz, hogy szájszerveikkel azt mechanikusan felsértsék (a rövid és közepes időtartamú rárepülésekkel is átvihetnek kórokozókat), így szerepük a betegség kiváltásában is jelentős.

A szerzők sztochasztikus számítógépes szimulációt végeztek (IBM AT számítógéppel, TURBO PASCAL nyelven), amelyben a jelen terepadatokat és egyes irodalmi adatokat használtak modellparaméterként. A szimulációs eredmények megerősítik, hogy a legyek önmagukban elégségesek ahhoz, hogy nyáron egy-egy gulya minden egyedében fenntartsanak egy szemfertőzést, ha eredetileg voltak a gulyában kórokozóval (pl. Moraxella bovis-szal) fertőzött egyedek. A legfontosabb szimulációs eredménynek az látszik, hogy még akkor is, ha a hosszú, több mint 1 perces légylátogatások (azaz a legyek okozta mechanikus szemsérülések) átlaga alig ingadozik, az egyes konkrét értékekben igen magas, kiugró értékek lehetnek.

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