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Factors affecting quality of temperature models for the pre-appearance interval of forensically useful insects

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ABSTRACT

In the case of many forensically important insects an interval preceding appearance of an insect stage on a corpse (called the pre-appearance interval or PAI) is strongly temperature-dependent. Accordingly, it was proposed to estimate PAI from temperature by using temperature models for PAI of particular insect species and temperature data specific for a given case. The quality of temperature models for PAI depends on the protocols for PAI field studies. In this article we analyze effects of sampling frequency and techniques, temperature data, as well as the size of a sample on the quality of PAI models. Models were created by using data from a largely replicated PAI field study, and their performance in estimation was tested with external body of PAI data. It was found that low frequency of insect sampling distinctly deteriorated temperature models for PAI. The effect of sampling techniques was clearly smaller. Temperature data from local weather station gave models of poor quality, however their retrospective correction clearly improved the models. Most importantly, current results demonstrate that sample size in PAI field studies may be substantially reduced, with no model deterioration. Samples consisting of 11–14 carcasses gave models of high quality, as long as the whole range of relevant temperatures was studied. Moreover, it was found that carcasses exposed in forests and carcasses exposed in early spring are particularly important, as they ensure that PAI data is collected at low temperatures. A preliminary best practice model for PAI field studies is given.

1. Introduction

Postmortem interval (PMI) or more frequently minimum PMI may be estimated from development or succession of insects on cadavers [1–3]. While estimating PMI from immature insects, it is convenient to divide it into the development interval and the pre-appearance interval (PAI) [4,5]. Most recent progress in the field refers to methods for the estimation of the development interval [e.g. 6–15]. As for the PAI, substantial progress was achieved in the area of volatile organic compounds attracting insects to carcasses [e.g. 16–20]. Moreover, recent works demonstrated that PAI of several forensically useful insects is dependent on temperature prevailing throughout this interval [21–24]. PAI was regularly found to decrease exponentially with an increase in temperature, which indicates that an exponential decrease is a general model for the association of PAI with temperature in forensically significant insects [22,24].

A recent progress in understanding the relation between PAI and temperature resulted in the proposition to estimate PAI from temperature [4,5,22–24]. These estimates require regression models capturing the dependence of PAI on average preceding temperatures in particular insect species. Such models were recently elaborated for many European species of Coleoptera [22], few European species of Diptera [24] and some Australian species of Diptera or Coleoptera [23]. The temperature models for PAI may be used in casework to estimate PAI simply by using temperatures specific for a given case. Such estimates of PAI may eventually be used to formulate estimates of PMI with a succession-based or a development-based approach [for more details see 4,5].

The temperature models for PAI may be created only from results of highly replicated pig carcass studies with a PAI-oriented design. Unfortunately, such studies are costly and time-consuming, so it would be useful to know how to effectively reduce their costs. Moreover, previous results suggest that differences in methods between various PAI studies may result in differences between

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resultant temperature models for PAI [4,5,22,23]. Accordingly, a more profound understanding of factors affecting quality of temperature models for PAI is needed. Such knowledge will help to specify best practice in the PAI field studies, similarly to other fields of forensic entomology [25–30].

It seems that the frequency with which insects are sampled during field studies is one of the most important factors. Sampling frequency was found to have a direct influence on the accuracy of temperature models for the development of forensically useful flies [26,31]. It may have similar effects on temperature models for PAI. We predict that the accuracy of PAI data decreases with decreasing frequency of insect sampling, which, in turn, affects the quality of temperature models for PAI. However, the extent of these effects and in particular robustness of the models to decreasing frequency needs to be investigated.

Another factor of probable high relevance is techniques of insect sampling. Several techniques were used in forensic field carrion studies, i.e. manual collections (by hand or entomological net) [e.g. 32–39], pitfall traps [e.g. 32,35–37,40], sticky traps [32,38], Malaise traps [41] or Schoenly traps [e.g. 42–44]. However, very few studies compared their performance in a forensic context. Schoenly et al. [32] demonstrated that the combination of pitfall traps and hand collections has the highest efficiency in catching forensically important taxa during field carcass experiments. It was also found that Schoenly traps are more efficient in catching adult flies than traditional manual collections [42]. It is however unclear whether and to what extent sampling techniques may influence the accuracy of PAI data and resultant temperature models for PAI. We predict that these effects exist and may have adverse influence on the quality of temperature models for PAI.

The quality of temperature data used in the model for PAI is also of probable high importance. On-site hourly measurements are preferable [22–24], however weather station data were also used and after retrospective correction gave surprisingly good models [4,5]. Consequently, it would be interesting to determine how seriously weather station data deteriorate models, and to what extent retrospective correction of temperature improves the models. It is of relevance that corrections of weather station temperatures were found to improve the accuracy with which these temperatures represent temperatures of the place where corpse has been found [45]. However some results suggest that these corrections have uncertain benefit when estimating PMI from the development of flies [46].

The last relevant factor of the current study is the number of carcasses comprising the sample used for modeling purposes. Because temperature cannot be manipulated in PAI field studies, a good design for such studies is of key importance. A reliable model for PAI should cover a broad range of temperatures, and to attain this goal researchers should address some issues concerning experimental design. In order to study PAI at different temperatures, recent experiments involved several placements of carcasses, separated in time [22–24]. For the same purpose carcasses were exposed in different habitats [22,24]. Moreover, carcasses may be distributed over different seasons, months and years. From this point of view several interesting questions arise. Firstly, is it more efficient to separate carcasses in time or space? Secondly, how should we separate carcasses in time or space to get the best range of temperatures? One may predict that both types of separation are important, however their effectiveness in collecting PAI data at different temperatures is probably different. Thirdly, what is the minimal number of carcasses that will give acceptable models? A recent work of Archer [23] revealed that for some insects quite good models may be created from as few as 10 carcasses, although their quality was worse than models from highly replicated studies [4,5,22,24]. So we predict that number of carcasses in PAI fields studies may be reduced to some extent without sacrificing the quality of resultant models.

2. Materials and methods

2.1. Data used in the analyses

All models were made by using PAI data from a large scale, PAI oriented pig carcass study. Details on the experimental design and protocols for handling of carcasses, sampling of insects and temperature measurements were specified by Matuszewski and Szafałowicz [22] and Matuszewski et al. [24]. Below there is just a brief description of the most important points. Thirty pig carcasses were separated in time: 18 April (four pigs), 15 June (six pigs), 4 July (six pigs), 21 July (four pigs), 16 August (four pigs) and 30 August (six pigs) of 2011. In each placement carcasses were distributed evenly among forest and open habitats. Insects were sampled three times a day for the first day after the exposure, two times a day for the following five days and afterwards once a day. Pitfall traps and manual collections (with entomological net and forceps) were employed. Ground level temperature was logged hourly at every carcass.

Performance of the models was tested by using data from an experiment on the effects of carcass mass and clothing on decomposition and succession of insects. Its methods were detailed in Matuszewski et al. [37], and below only the most important points for the current work are given. Twenty-four pig carcasses were grouped into three blocks which were separated in time: 17 May, 16 July and 27 August of 2012. Each block consisted of clothed and unclothed carcasses of four different masses (mass range: 7–64 kg). Carcasses were exposed in xerothermic rural grasslands. Insects were sampled once a day until about 20th day post-mortem, afterwards sampling was less frequent. Pitfall traps and manual collections (with entomological nets and forceps) were employed. Ground level temperature was logged hourly at every carcass.

2.2. Analyses

General scheme for analyses. All analyses were performed according to the same general scheme. In the first step PAI data were prepared. In all cases these data came from the PAI oriented pig carcass study, which was described in the previous section. These data were used for making control models from unchanged data and experimental models from modified data. Details of particular modifications are described in the following paragraphs. In the second step control and experimental models were created. As per our previous results [22], an exponential model with asymptote displaced from zero ($\mathrm{PAI} = c + e^{(b0+b1^{*}\mathrm{temperature})}$) was fitted to the data in all analyses. Models were created for these taxa which were previously found to display a close association between PAI and temperature ($r^2 > 0.8$). They were adult and larval *Necrodes littoralis* L. (Coleoptera: Silphidae), adult and larval *Creophilus maxillosus* L., adult *Philonthus politus* L. (Coleoptera: Staphylinidae), adult *Necrobia rufipes* De Geer (Coleoptera: Cleridae), adult *Saprinus semistriatus* Scriba and adult *Saprinus planiusculus* Motch. (Coleoptera: Histeridae), adult and the egg stage of *Stearibia nigriceps* Meigen (Diptera: Piophilidae) [4,5,22,24]. For each taxon control and experimental models were made, and in the third step, models were compared according to their fit (r^2) and the c parameter. For this purpose the non-parametric Friedman rank test was used. In the last step the performance of models with the estimation task was tested by using the second body of data from the previous section. PAI was estimated by using the models and was compared against the PAI from the original study. Finally, models were compared according to the relative error of estimation and again Friedman rank test was