Available Online at ESci Journals
International Journal of Entomological Research
ISSN: 2310-3906 (Online), 2310-5119 (Print)
http://www.escijournals.net/IJER

USE OF TEMPERATURE MODEL IN ESTIMATING POSTMORTEM INTERVAL IN FORENSIC ENTOMOLOGY

Tock H. Chua*
School of Medicine, Malaysia Sabah University, Malaysia.

A B S T R A C T

The feasibility of using a temperature model with the developmental rates of *Chrysomya megacephala* and *C. rufifacies* to estimate post mortem interval (PMI) was explored with six recent forensic cases in Kota Kinabalu, Malaysia. The PMI obtained from the model was compared to that calculated from the observed half hourly air temperature data recorded at the Kota Kinabalu Airport weather station. The results indicate that there are only minor differences between the PMI estimates obtained from the model and observed temperatures. We conclude that this temperature model could provide reasonable PMI values, especially where observed temperatures are not available. Other possible uses of the temperature model in forensic work are also discussed.

Keywords: Forensic Science, Forensic entomology, postmortem interval, temperature model.

INTRODUCTION

Forensically important insects have been used in estimating postmortem interval (PMI) based on species and life stages of specimens recovered from body or at crime scene. It is known that the development of immature stages of insects is temperature dependent (Ismail *et al.*, 2007; Firdaus *et al.*, 2009; Nabity *et al.*, 2006). Thus, it is critical to have accurate and reliable data on larval stage development, and how development is affected by temperature and relative humidity (Ismail *et al.*, 2007). The accuracy of the PMI estimate is only as good as the data available. This has been shown using computer sensitivity analysis (Slone *et al.*, 2006), indicating that the most sensitive parameter in PMI estimation is the growth rate of the larvae, followed closely by air temperature, although the latter becomes less important as the larval mass grows larger and has better internal temperature regulation.

Suggestions for improving PMI estimations include using the development data generated at a temperature close to that at a death scene (Lord *et al.*, 1994; Anderson, 1997). This has been confirmed by Doudrel *et al.* (2010) who performed a series of computer simulations and concluded that using ambient temperatures estimated from linear regression models based on data from meteorological stations may not always provide accurate PMI, as compared to the onsite temperatures recorded by data loggers.

In most cases, ideal conditions such as constant temperature and available on-site temperatures are rarely encountered. As the diurnal temperature fluctuates in a 24 hr cycle, development rates of flies would vary accordingly. If the temperature varies greatly throughout the day, using the mean daily temperature could lead to less than accurate PMI estimate especially if there is a sudden change in temperature (Ames & Turner, 2003). Furthermore, the forensic investigators have the disadvantage of calculating the PMI retrospectively (Smith, 1986; Arnaldos *et al.,* 2005).

Studies on the developmental rates of forensic insects are usually conducted in the laboratory under constant temperatures and relative humidity (for examples in Malaysia, see Ismail *et al.* (2007) and Firdaus *et al*. (2009)). Similar studies in the field are rare; a notable example is the work of Sukontason *et al.* (2008) who studied the developmental rate of *C. megacephala* and *C. rufifacies* (Fabricius) under natural ambient

* Corresponding Author:
Email: chuath@gmail.com

temperature and a natural light–dark photoperiod in Chiang Mai province, Northern Thailand during 2000–2001. Their results indicated that larvae of both species developed rapidly in the summer but grew slower in the rainy season and winter. Pupariation of *C. megacephala* initiated at 84 h -168 h (mean temperatures 31.4°C-23.8 ˚C), while pupariation of *C. rufifacies* initiated at 96 h – 192 h (mean temperature 27.4°C -23.8°C). Wells & Kurahashi (1994) had earlier reported pupariation of *C. megacephala* at 144 h, from experiments conducted at a controlled temperature of 27°C and light conditions of 16L:8D h. The question whether the laboratory data generated at constant temperatures are reliable for PMI estimation has been previously examined by Anderson (2000).

We present here a method which uses a temperature model for calculating PMI. This method takes into consideration the changing environmental temperature at half-hourly intervals. Our main objective is to investigate if the temperature model can provide sufficiently accurate temperatures which can be used to produce an acceptable PMI. We tested the model in six recent forensic cases in Kota Kinabalu (05°59'N, 116°04'E, 8m above sea level) which is the capital of Sabah, Malaysia.

MATERIALS AND METHODS

The number of forensic cases with fly larvae in Kota Kinabalu is low and only six cases were available in 2011-2012. PMI was calculated for these six forensic cases using both the half hourly temperature generated by the temperature model and the observed half hourly air temperature data recorded by Kota Kinabalu Airport weather station.

Forensic cases in Kota Kinabalu: In 2011-2012, insect larvae were collected from the six corpses found in Kota Kinabalu and its vicinity. Details of these caseworks are given in Table 1.

Table 1. Details of the six forensic cases in Kota Kinabalu (Malaysia) and its vicinity, from which insect larvae had been collected.

Case	Date body discovered	Details	Forensic insects collected
1	21 March 2011	Female, 42 years old, body found in scrub area.	*C. megacephala* , *C. rufifacies*, late 3rd instar larvae
2	13 April 2011	Elderly male, 86 years old; body found on bed in wooden hut, apparently died in sleep.	*C. megacephala*, *C. rufifacies*, late 3rd instar larvae.
3	23 Sept 2011	Female, 62 years old, found dead in wooden house.	*C. megacephala*, *C. rufifacies*, 3rd instar larvae.
4	1 Mar 2012	Male, 44 years old; body found at seaside	*C. megacephala*, late 3rd instar larvae.
5	22 Mar 2012	Male	*C. megacephala*, late 3rd instar larvae.
6	2 May 2012	Male, 74 years old, body found in rubber plantation	*C. rufifacies* , late 3rd instar larvae

The larvae were identified as *C. megacephala* and *C. rufifacies*. These two species are most common and possibly the most important insects encountered in many forensic cases in Malaysia (Firdaus *et al*., 2002; Lee *et al.*, 2004) and in neighbouring Thailand (Sukontason *et al.*, 2001, 2008).

Air temperature model: The temperature model used was based on a sinusoidal submodel for daytime and a decreasing exponential submodel for the night (Parton & Logan, 1981; Paaijmans *et al*., 2009).

For daytime where $t_{rise} \le t < t_{set}$, the sinusoidal submodel is given by:

$$T_t = T_{min} + (T_{max} - T_{min}) \sin[\pi (t - 12 + ½D) / (D + 2p)]$$

For nighttime where $t_{set} \le t < t_{rise}$, the decaying exponential submodel is:

$$T_t = [T_{min} - T_{set} \exp(-N/\tau) + (T_{set} - T_{min}) \exp(-(t - t_{set})/\tau)] / [1 - \exp(-N/\tau)]$$ where

T_{min}, T_{max}: minimum and maximum daily air temperature

T_{set}: temperature at sunset

t_{rise}, t_{set} : time (hours) of sunrise, sunset

D, N: hours of day, night= 12, 12

τ: nocturnal night constant =3

p: time duration between solar noon and maximum air temperature =4

The values of other daily varying parameters used in the model for the periods of the forensic cases are given in Table 2. Correlation analysis was also performed between the observed and model-generated half-hourly temperatures to check on the validity of the temperature model.

Table 2. Parameter values for various dates used in the temperature model for predicting half hourly temperatures.

Cases	Date	mean and range (T_{min}, T_{max}) temp ˚C	Sunrise time (hrs) (t_{rise})	Sunset time (hrs) (t_{set})	Sunset temp˚C (T_{set})
Case 1	22 Mar 2011	25.4 (23-29)	0619	1826	23
	21 Mar 2011	25.8 (23-31)	0620	1826	24
	20 Mar2011	26.2 (24-30)	0620	1826	24
	19 Mar 2011	27.0 (25-30)	0621	1826	27
Case 2	13 Apr 2011	26.2 (23-33)	0609	1823	25
	12 Apr 2011	27.3 (23-31)	0609	1823	27
	11 Apr 2011	27.3 (24-32)	0610	1823	28
	10 Apr 2011	26.9 (24-34)	0610	1823	28
Case 3	23 Sep 2011	27.8 (23-33)	0605	1811	29
	22 Sep 2011	27.0 (23-31)	0605	1812	28
	21 Sep 2011	26.7 (24-32)	0605	1813	27
	20 Sep 2011	27.5 (24-34)	0606	1814	25
Case 4	1 Mar 2012	27.9 (24-33)	0628	1828	28
	29 Feb 2012	28.0 (23-32)	0628	1828	28
	28 Feb 2012	26.4 (23-31)	0629	1828	24
	27 Feb 2012	26.8 (24-33)	0629	1828	24
Case 5	22 Mar 2012	25.8 (23-31)	0619	1826	24
	20 Mar 2012	26.2 (24-31)	0619	1826	24
	19 Mar 2012	27.9 (24-33)	0619	1826	28
	18 Mar 2012	28.0 (25-32)	0620	1828	28
Case 6	2 May 2012	28.6 (25-32)	0603	1823	30
	1 May 2012	27.2 (24-32)	0603	1823	26
	30 Apr 2012	28.2 (25-34)	0603	1823	26
	29 Apr 2012	28.0 (24-32)	0603	1823	30

Estimation of PMI: The degree hour of development (*i.e.,* the product of temperature and duration in hours) of the insect at each half hour interval was calculated and accumulated. The mean accumulated day hours (ADH) used in the computer simulation for *C. megacephala* (27-33 ˚C) for egg, three larval instars, larval III extended, and pupa are 275.8, 396.0, 441.0, 927.0, 853.0, and 2917.9, respectively, yielding a total ADH of 5810.7. The corresponding values for *C. rufifacies* are: 301.5, 543.0, 357.0, 873.0, 1270.3, 290.5 and 6295.3.

All computations were carried out using Microsoft Office Excel 2010 Software.

RESULTS

The temperature model generated temperature values were similar to the observed temperatures, and correlation analysis of predicted and observed temperatures yielded high correlation coefficients of 0.88-0.96 (Table 3).

The correlation was conducted for 4 days (since this is approximately the time lapse before the body was discovered) except for case 5 in which the body was discovered much earlier. The letter n indicates the number of half-hour temperatures used in the correlation analysis. All values of correlation coefficient are significant ($P<0.001$).

Table 3: Correlation analysis of model-predicted and observed half-hourly temperatures for the six forensic cases.

Case	Date	Correlation coefficient	n
1	18mar-21 Mar 2011	0.88	192
2	10 apri-13 apri 2011	0.89	192
3	20sep-23sept2011	0.93	192
4	27feb-1 mar 2012	0.96	192
5	20mar-22 mar 2012	0.90	144
6	29apri-2 may 2012	0.96	192

The PMIs estimated from both the model generated temperatures and the observed temperatures differed only slightly, and the differences between the estimated values ranged from 0.6 – 3.4 hr (Table 4). The differences appear to depend on the prevailing temperature in that the difference (y) between the lower PMIs estimated using the two sets of temperatures is related to the mean temperature (x) for the duration in each casework by the equation: $y=1.67x-43.8$ ($P<0.05$).

Table 4: Comparison of PMI (hours) estimated using (a) observed mean daily air temperatures and (b) half-hourly air temperatures predicted by the temperature model. Regression of difference between lower estimates (y) on the mean of daily mean temperatures for the specified date (x) yielded the equation: y=1.67x -43.8 (P<0.05).

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
PMI (hours) estimated using	Observed. mean daily temperatures	73.6-82.9	98.5 -105.3	71.6-102.6	74.8-105.0	44.3-44.9	25.9-48.6
	Predicted half hourly air temp from model	75.0-84.0	100.0-108.0	74.0-105.0	76.3-107.5	45.0-45.5	28.0-51.5
Difference between higher estimates		1.1	2.7	2.4	2.5	0.6	3.4
Difference between lower estimates (y)		1.4	1.5	2.4	1.5	0.7	2.1
Mean of daily mean temperatures for the specified date (x)		27.3 (18mar-21 Mar 2011)	27.6 (10 apri-13 apri 2011)	27.8 (20sep-23sept2011)	27.3 (27feb-1 mar 2012)	27.0 (20mar-22 mar 2012)	28.5 (29apri-2 may 2012)

DISCUSSION

The temperature model appears to give a sufficiently accurate forecast for temperatures as confirmed by the correlation analysis. The predicted half-hourly temperatures allow the incorporation of the diurnal temperature variations which would affect the larval developmental rates and thus the PMI estimation.

The PMI estimated by using the half-hourly temperatures from the model and the temperature-dependent developmental rates of *C. megacephala* and *C. rufifacies* are very similar to those calculated from using the observed temperature, thus validating the temperature model.

The mean daily temperatures can also be computed from the model and used in PMI estimation. In tropical countries like Malaysia where there is a small daily temperature range (5 – 10 ˚C), the use of the daily mean temperature may yield acceptable PMI in some cases. If the temperature range is greater, the difference between the PMI estimates from mean daily temperature and half- hourly temperature could increase when there are sudden thunderstorms and/or rain, for example. Similarly, the increase could be significant in temperate countries where low temperatures may occur during sudden summer cold spells resulting in greater ADH (Ames & Turner, 2003).

Various studies have shown that the use of mean daily temperature may provide reasonable PMI estimates. Byrd & Butler (1998) suggested that for *C. rufifacies*, developmental data obtained under a constant temperature (25 ˚C) could be applied to cyclic temperature conditions (15.6 to 30 ˚C) , as long as the mean temperature values were comparable. Similarly, Dadour *et al.* (2001) found that there was no significant difference in the developmental rate of *Calliphora dubia* at fluctuating temperatures of 30°C and 19°C, when compared with the mean constant of 24°C. Dadour *et al.* suggested that this is because both temperatures of the fluctuating regime lie within the threshold and optimum temperature for *C. dubia* development. This implies that two conditions are required before a mean constant temperature could be used in the estimation of a good PMI. These are (a) the mean value used in the estimation is comparable to the mean of the fluctuating temperatures, and (b) the fluctuating regime lie within the threshold and optimum temperature for the species.

An advantage of using a temperature model in forensic work is that the model can be used to retrospectively estimate the PMI at various localities which have different temperatures. Parameter values including time of sunset and sunrise, maximum temperature at sunset, *etc.* can be easily obtained and added. The effect of an unexpected temperature change on the PMI in a given scenario can be modeled quickly, *e.g.*, the effect of a sudden thunder storm in the tropics or a cold summer spell in the temperate region during the development period, thus reducing possible PMI error highlighted previously (Ames & Turner, 2003). Furthermore, in a possible scenario where a body kept in a cooler for a day or two has been moved to a warmer area, the model would still be useful in estimating the PMI by inputting different model parameter values for the different days.

Finally, forensic entomologists tend to give values of PMI in terms of whole days, possibly because of the method of calculation. For example, in the Asian region, Firdaus *et al.* (2007) estimated PMI of 4-5 days from third stage larvae of *C. megacephala* and *C. rufifacies*, while Sukontaxon *et al.* (2001) arrived at a PMI of 4 days. Using the temperature model, the PMI can obtained and presented in terms of hours, which might prove useful in certain forensic investigations.

ACKNOWLEDGMENTS

I thank Dr. Jessie Hui and Ivy Eddie of the Forensic Department of Queen Elizabeth Hospital, Kota Kinabalu, Sabah who collected the fly larvae for me, and the Universiti Malaysia Sabah for general facilities to conduct this research.

REFERENCES

Ames, C. and Turner, B. 2003. Low temperature episodes in development of blowflies: implications for postmortem interval estimation. Med. Vet. Entomol. 17: 178–186.

Anderson, G.S. 1997. The use of insects to determine time of decapitation: a case-study from British Columbia. J. Forensic Sci. 42: 947–950.

Anderson, G.S. 2000. Minimum and maximum development rates of some forensically important Calliphoridae Diptera. J. Forensic Sci. 45: 824–832.

Arnaldos, M.I., Garcia, M.D., Romera, E., Presa, J.J. and Luna, A. 2005. Estimation of postmortem interval in real based on experimentally obtained entomological evidence. Forensic Sci. Int. 149: 57–65.

Byrd, J.H. and Butler, J.F. 1998. Effects of temperature on *Chrysomya rufifacies* Diptera: Calliphoridae development. J. Med. Entomol. 35: 353-358.

Dadour, I.R., Cook, D.F., Fissioli, J.N. and Bailey, W.J. 2001. Forensic entomology: application, education and research in Western Australia. Forensic Sci. Int. 120:48–52.

Dourel, L., Pasquerault, T., Gaudry, E. and Vincent, B. 2010. Using estimated on-site ambient temperature has uncertain benefit when estimating postmortem interval. Psyche, article ID 610639, 7 pages, doi: 10.1155/2010/610639.

Firdaus, A., Anita, T., Marwi, M.A., Noor Hayati, M.A., Syamsa, R.A., Zuha, R. M. and Omar, B. 2009. Effect of temperatures on larval development of *Chrysomya megacephala* Fabricius and *Chrysomya rufifacies*Macquart Diptera: Calliphoridae:application in forensic science. J. Sains Kesihatan Malaysia 7: 89-96.

Firdaus, A., Marwi, M.A., Jeffery, J., Hamid, N.A., Zuha, R.M. and Omar, B. 2007. Review of Forensic Entomology Cases from Kuala Lumpur Hospital and Hospital Universiti Kebangsaan Malaysia, 2002. J. Trop. Med. Parasitol. 30: 51-54.

Ismail, M.I., Osman, K., Ong, H.K., Hassan, N., Elias, E., Ambia, K.M., Ghazali, A.R., Mohamed, J. and Omar, B. 2007. Accelerating *Chrysomya megacephala* maggot growth for forensic entomology cases. J. Sains Kesihatan Malaysia 5: 17-26.

Lee, H.L., Krishnasamy, M., Abdullah, A.G. and Jeffery, J. 2004. Review of forensically important entomological specimens in the period of 1972-2002. Trop. Biomed. Suppl. 2004: 69-75.

Lord, W.D., Goff, M.L., Adkins, T.R. and Haskell, N.H. 1994. The black soldier fly *Hermetia illucens* Diptera: Stratiomyidae as a potential measure of human postmortem interval: observations and case histories. J. Forensic Sci. 39: 215–222.

Nabity, P.D., Higley, L.G. and Heng-Moss, T.M. 2006. Effects of temperature on development of *Phormia regina* Diptera: Calliphoridae and use of developmental data in determining time intervals in Forensic Entomology. J. Med. Entomol. 43: 1276-1286.

Paaijmans, K.P., Read, A.F. and Thomas, M.B. 2009. Understanding the link between malaria risk and climate. Proc. Natl Acad. Sci. 106: 13844-13849.

Parton, W.J. and Logan, J.A. 1981. A model for diurnal variation in soil and air temperature. Agri. Meteorol. 23: 205-216.

Slone, D.H., Gruner, S.V. and Allen, J.C. 2005. Assessing error in PMI prediction using a forensic Entomological computer model, https://www.ncjrs.gov/pdffiles1/nij/grants /211760.pdf assessed 6 Dec 2011.

Smith, K.G.V. 1986. A Manual of Forensic Entomology. Cornell University Press, Ithaca, New York.

Sukontason, K., Piangjai, S., Siriwattanarungsee, S. and Sukontason, K.L. 2008. Morphology and developmental rate of blowflies *Chrysomya megacephala* and *Chrysomya rufifacies* in Thailand: application in forensic entomology. Parasitol. Res. 102: 1207–1216.

Sukontason, K.L., Sukontason, K., Narongchai, P., Lertthamnongtham, S., Piangjai, S. and Olson, J.K. 2001. *Chrysomya rufifacies* Macquart as a forensically-important fly species in Thailand: a case report. J. Vector Ecol. 26: 162–164.

Wells, J.D. and Kurahashi, H. 1994. *Chrysomya megacephala* Fabricius Diptera: Calliphoridae developmental: rate, variation and implications for forensic entomology. Jpn J. Sanit. Zool. 45: 303–309.