

Estimation of temperature-dependent growth profiles of fly larvae with application to criminology

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(Joint work with D. Pigoli, J. A. D. Aston, A. Mazumder, C. Richards, M.J.R. Hall)

Café de l'IMT, Décembre 2022

Outdoor crime scene



Outdoor crime scene



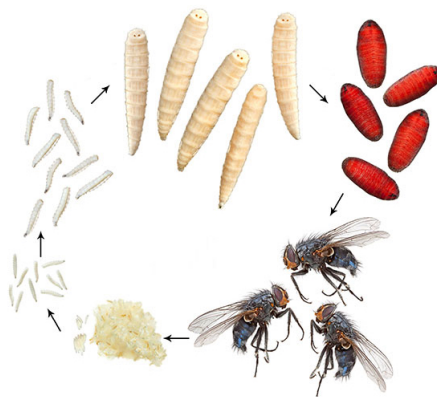
- **post-mortem time (pmi)**

=

time difference between death and
discovery of corpses

- Important issue : **How estimating
pmi beyond a few days ?**

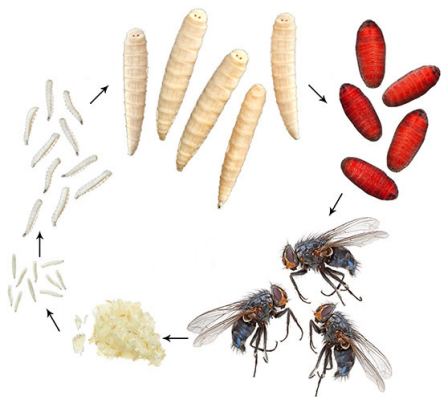
Solution : forensic entomology



→ BLOWFLY LIFE CYCLE (*calliphora vicina*)

- eggs
- instar larvae (with two moults)
- pupation stage (cuticle contracts and hardens into a shiny brown puparium)
- adult fly

→ BLOWFLY LIFE CYCLE
(calliphora vicina)



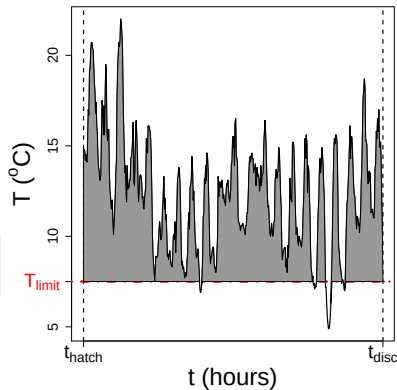
- eggs
- instar larvae (with two moults)
- pupation stage (cuticle contracts and hardens into a shiny brown puparium)
- adult fly

- blow flies arrive within minutes to lay eggs on a cadaver
- $\text{pmi} \approx \text{oldest larva (at most advanced developmental stage)} + \text{time to hatching}$

Current investigator approach for estimating *pmi*

- t_{hatch} = hatching time
- t_{disc} = discovery time of corpse

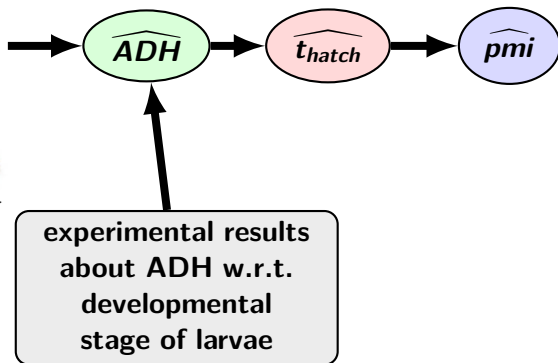
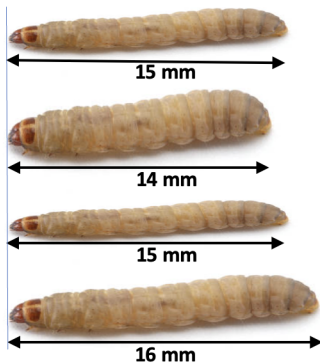
Accumulated Degree Hours (ADH)
= grey area



Interpretation

ADH = amount of thermal energy available to the larva

Current investigator approach : ADH method



Our approach

$$pmi \simeq \underbrace{t_{disc} - t_{hatch}}_{\text{statistical method}} + \underbrace{t_{hatch} - t_{egg\ laying}}_{\text{entomology}}$$

maggot growth profile

 $+$

↓ ↓

↓ ↓

pmi = maggot age
+ time to hatching

Available data

Crime scene data

Investigators

- ① collect larvae from the body at the most advanced developmental stage
- ② record "continuously" temperatures at the crime scene

Available data

Crime scene data

Investigators

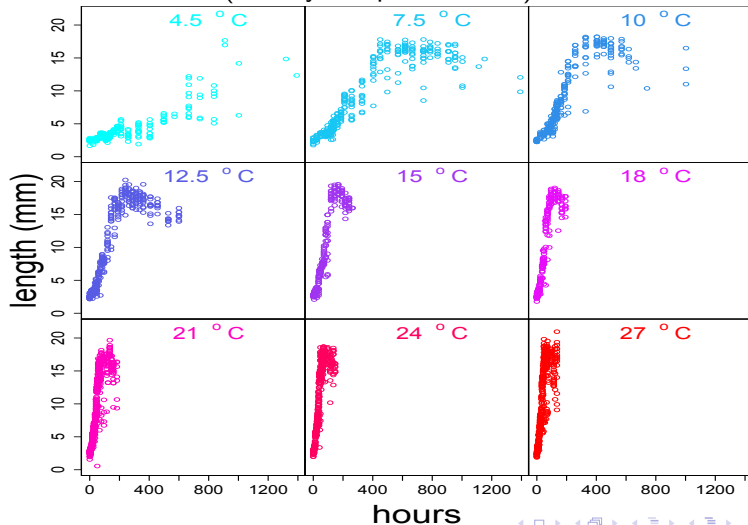
- ① collect larvae from the body at the most advanced developmental stage
- ② record "continuously" temperatures at the crime scene

Additional data

- temperatures from the closest wheather station
↳ recover past temperatures at the crime scene
- Experimental developmental larvae data

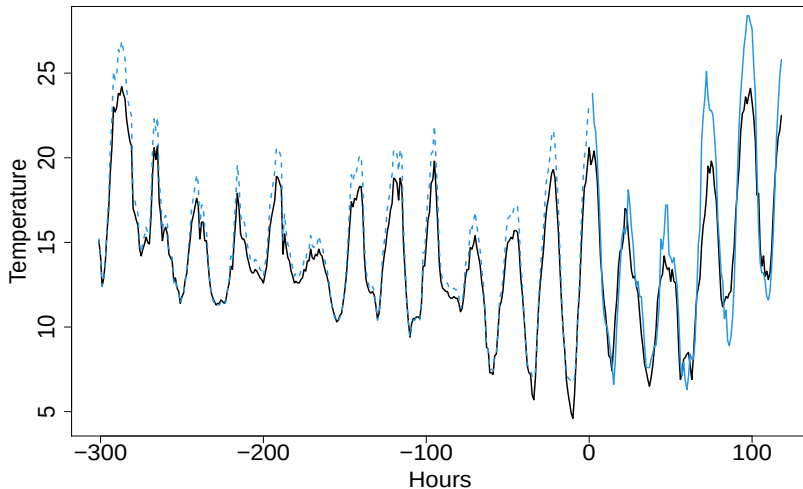
Available data

Experimental developmental larvae data depends on temperature
(blowfly *calliphora vicina*)



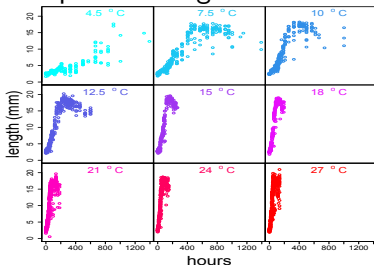
Available data

Temperatures profile at crime scene

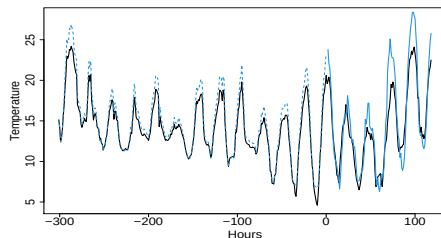


Statistical challenge

experimental growth data

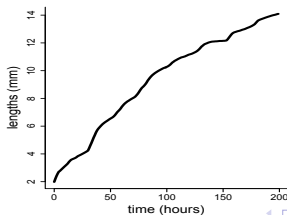


temperature profile at crime scene



+

How estimating growth profile
with varying temperatures



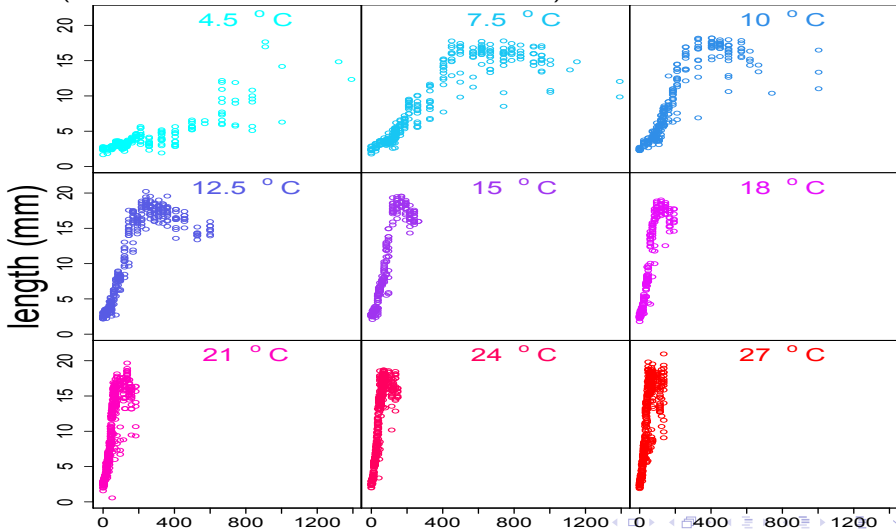
?

Four-steps estimating procedure

- 1 Smoothing experimental developmental data
- 2 Decompose growth profiles into aligned growth profiles and warping functions
- 3 Estimate constant temperature growth profile and its derivative at any temperature
- 4 Build the varying temperature growth profile from a dynamic model and estimate pmi

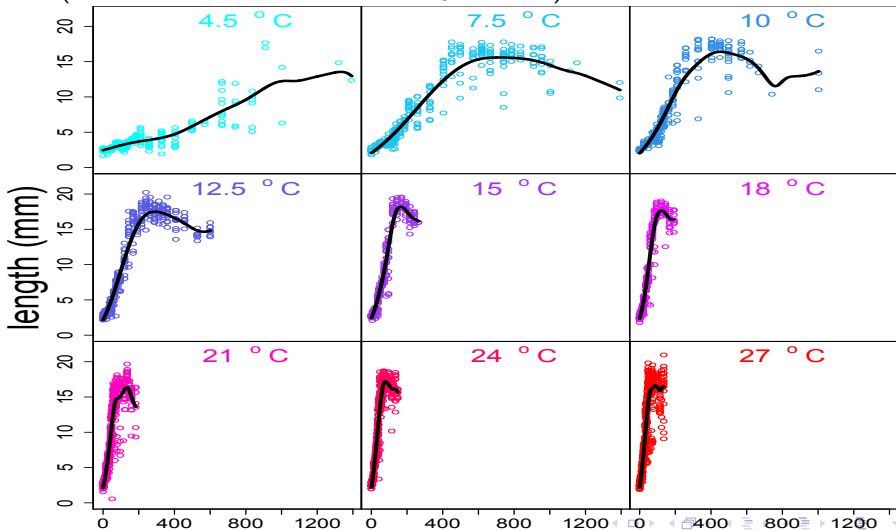
Step 1 : smoothing experimental developmental data

experimental data at constant temperature
($T_1 = 4.5^\circ\text{C}$, $T_2 = 7.5^\circ\text{C}$, ..., $T_9 = 27^\circ\text{C}$)



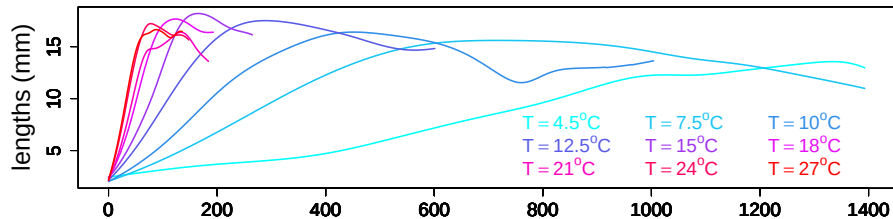
Step 1 : smoothing experimental developmental data

growth profiles $\tilde{L}_{T_1}, \dots, \tilde{L}_{T_9}$ at constant temperature
($T_1 = 4.5^\circ\text{C}$, $T_2 = 7.5^\circ\text{C}$, ..., $T_9 = 27^\circ\text{C}$)

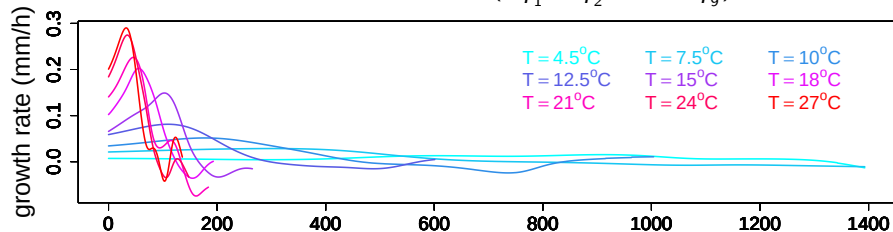


Step 1 : growth profiles + growth rate profiles

growth profiles ($\tilde{L}_{T_1}, \tilde{L}_{T_2}, \dots, \tilde{L}_{T_9}$)



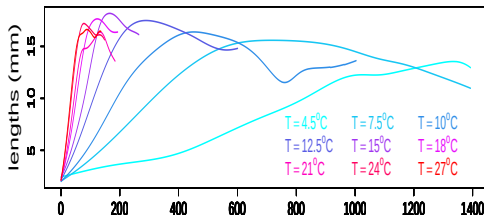
growth rate profiles ($\tilde{L}'_{T_1}, \tilde{L}'_{T_2}, \dots, \tilde{L}'_{T_9}$)



Step 2 : growth profile = aligned profile ○ warping fct

benchmark growth profiles

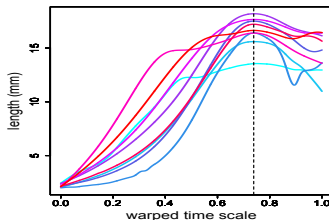
$$\tilde{L}_{T_1}(t) = \tilde{S}_{T_1} \circ \tilde{W}_{T_1}(t/t_{pup}^1), \dots, \tilde{L}_{T_9}(t) = \tilde{S}_{T_9} \circ \tilde{W}_{T_9}(t/t_{pup}^9)$$



=

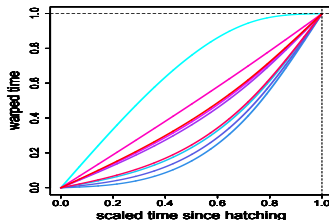
bench. aligned profiles

$$\tilde{S}_{T_1}, \dots, \tilde{S}_{T_9}$$



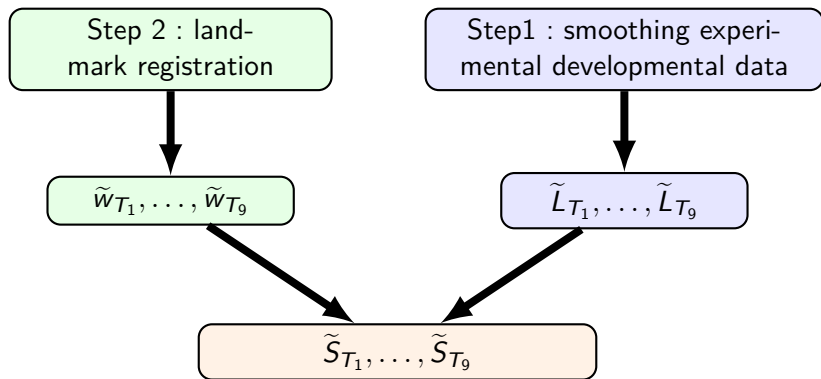
bench. warping functions

$$\tilde{W}_{T_1}, \dots, \tilde{W}_{T_9}$$



○

Step 2 : estimation of benchmark aligned profiles



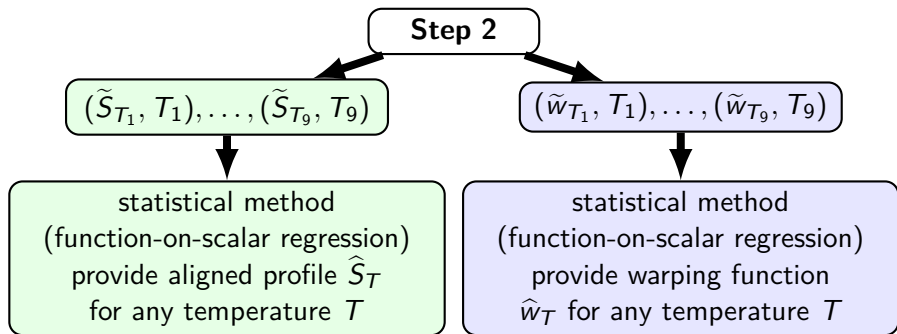
Step 3 : **growth profile** at any temperature T

Step 2

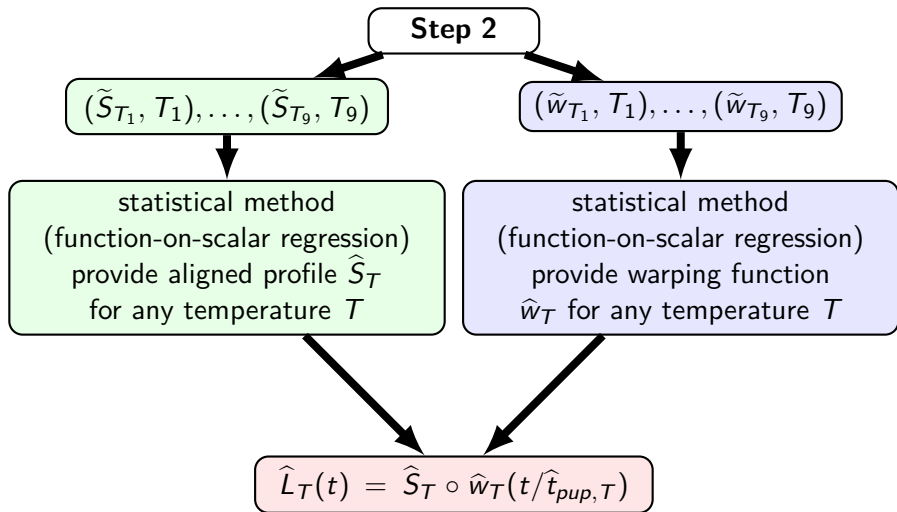
$(\tilde{S}_{T_1}, T_1), \dots, (\tilde{S}_{T_9}, T_9)$

statistical method
(function-on-scalar regression)
provide aligned profile $\hat{S}_T$
for any temperature T

Step 3 : **growth profile** at any temperature T

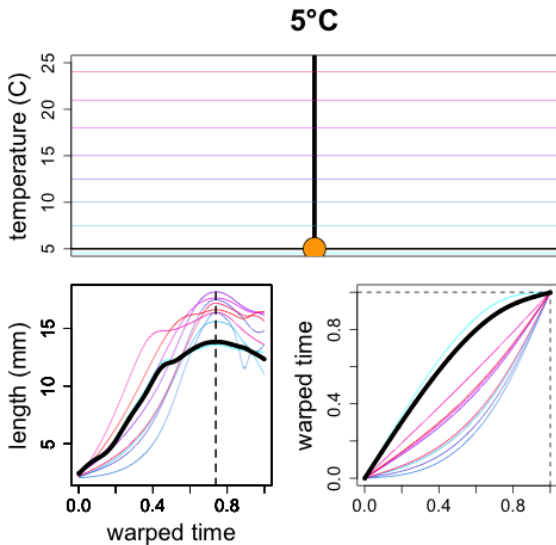


Step 3 : **growth profile** at any temperature T

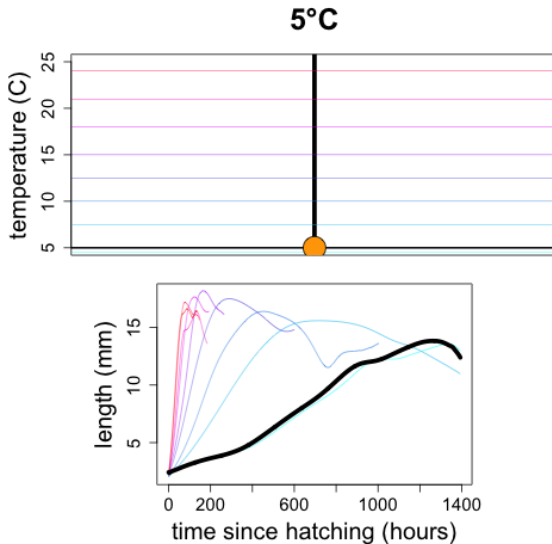


where $\hat{t}_{pup,T}$ estimator based on $(t_{pup}^1, t_1), \dots, (t_{pup}^9, T_9)$

Step3 : aligned profiles and warping fct at any temp. T



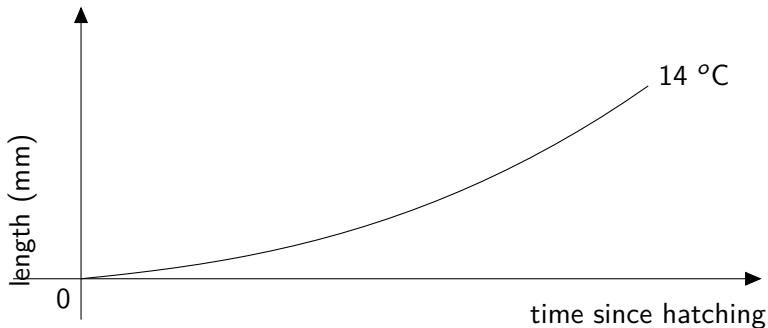
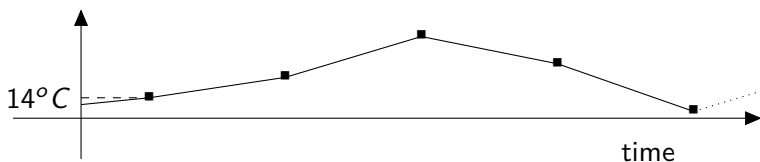
Step3 : growth profile at any temperature T



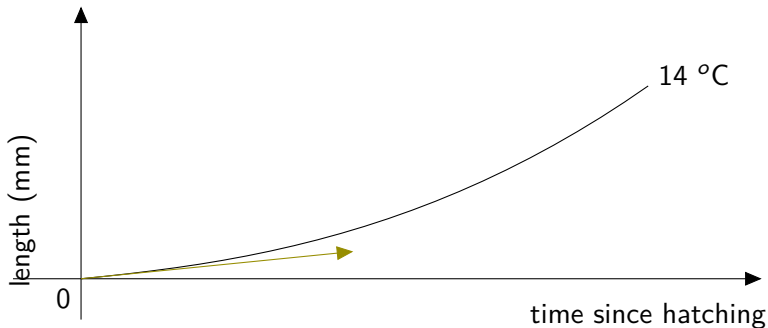
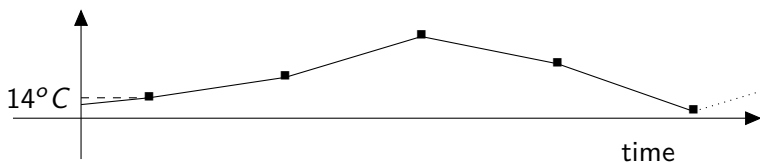
Step 3 : **growth rate profile** at any temp. T

For any T , $\hat{S}'_T$, $\hat{w}_T$, $\hat{w}'_T$ and $\hat{t}_{pup,T} \longrightarrow \hat{L}'_T$

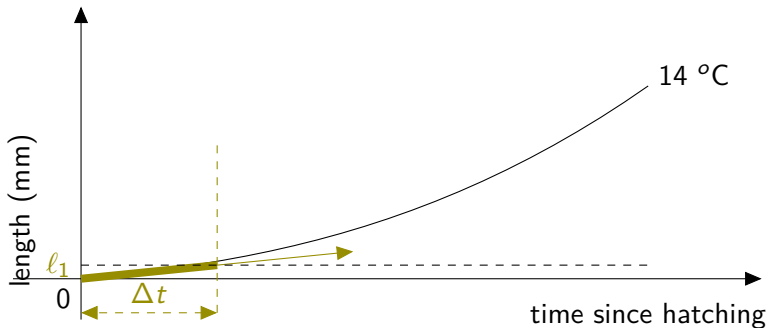
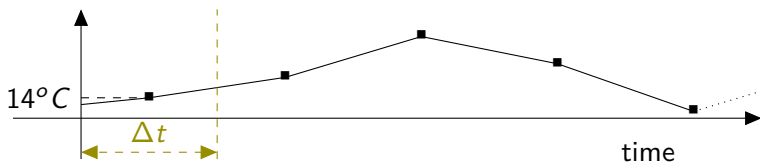
Step 4 : temperature-dependent growth profile



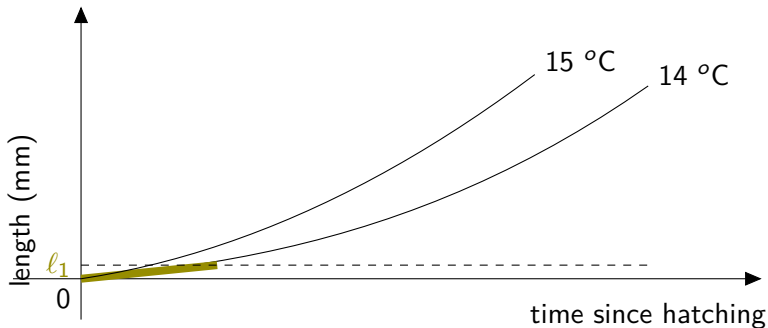
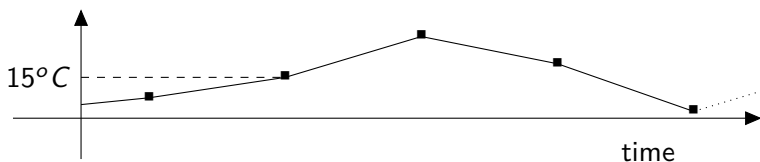
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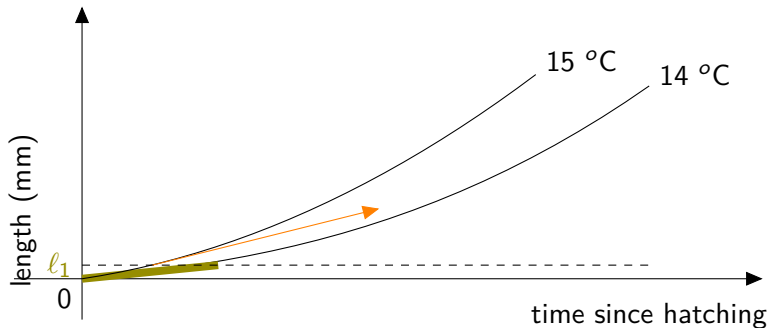
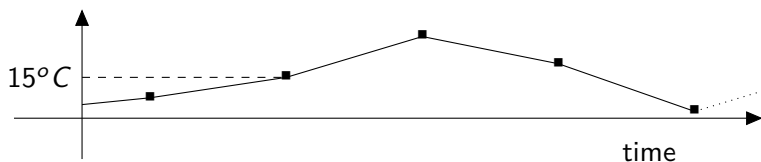
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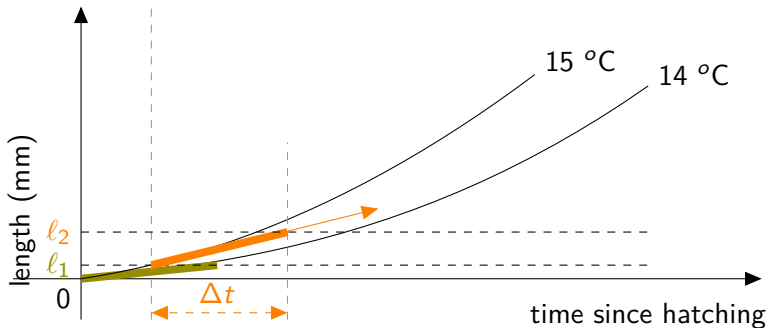
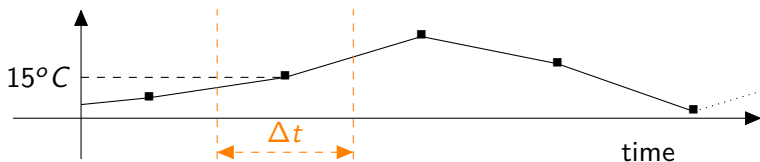
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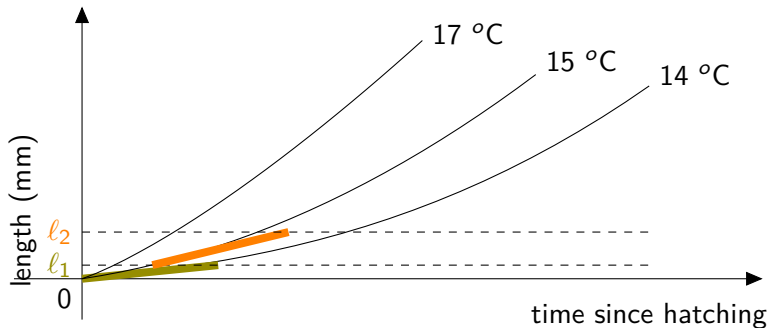
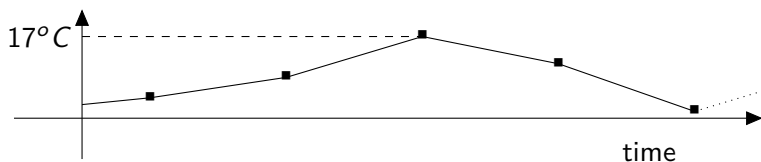
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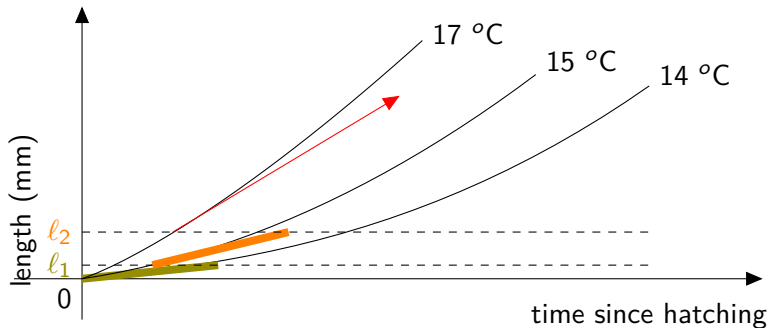
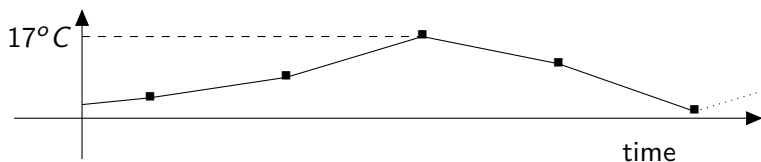
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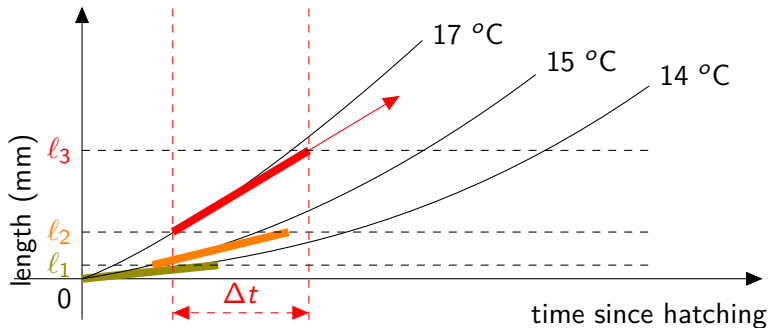
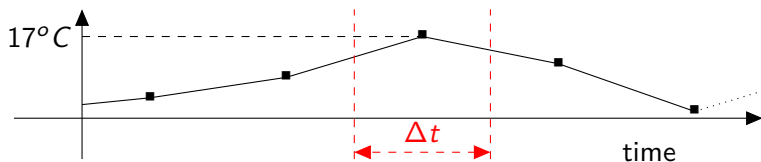
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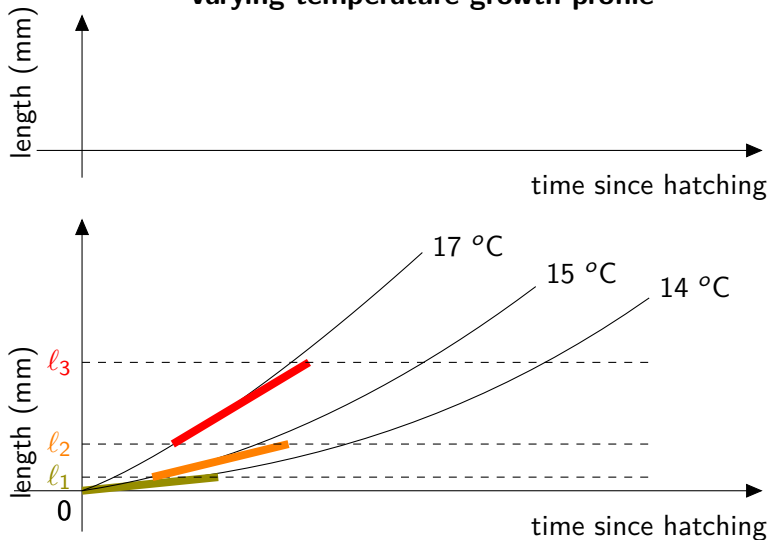


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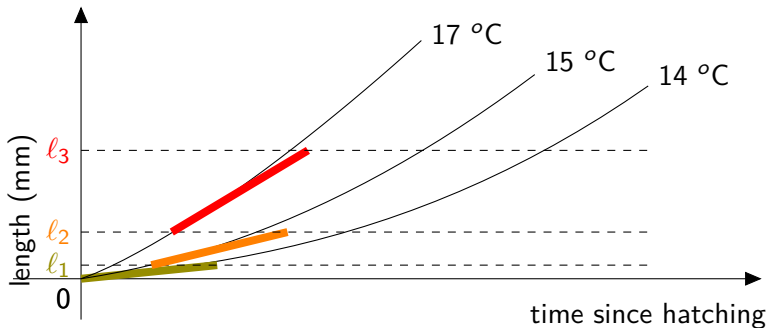
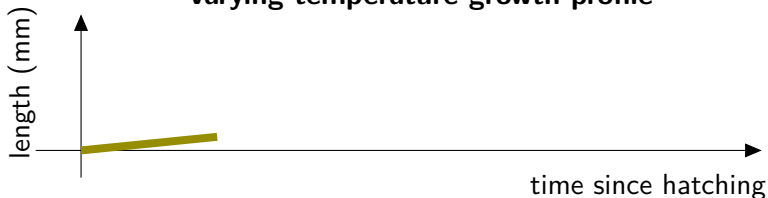
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varying temperature growth profile

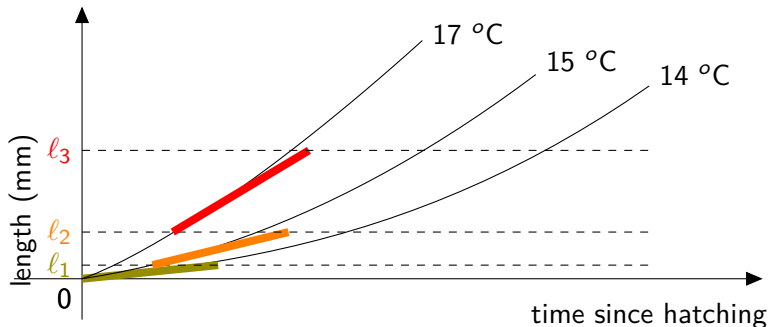
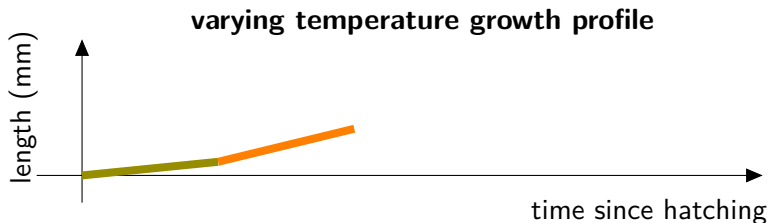


Step 4 : temperature-dependent growth profile

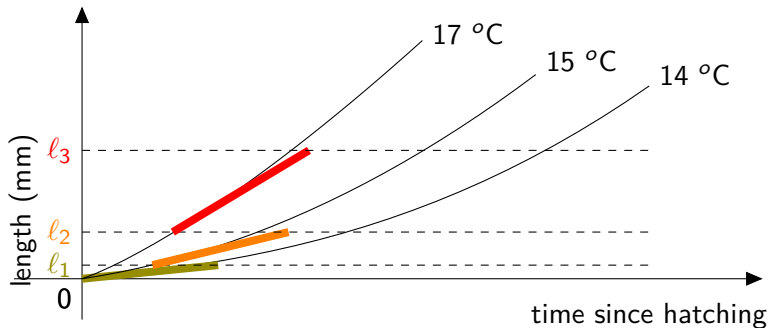
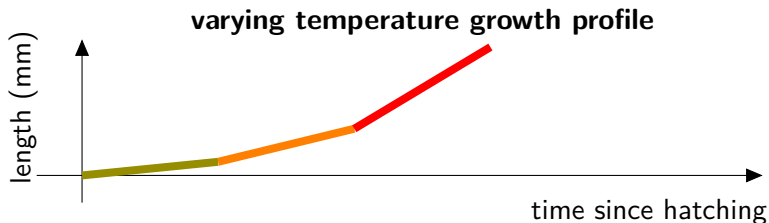
varying temperature growth profile



Step 4 : temperature-dependent growth profile



Step 4 : temperature-dependent growth profile



Step 4 : Estimated varying temp. growth profile

$$L(t) - L(0) = \int_0^t L'_{T_v} \circ L_{T_v}^{-1} \circ L(v) dv$$

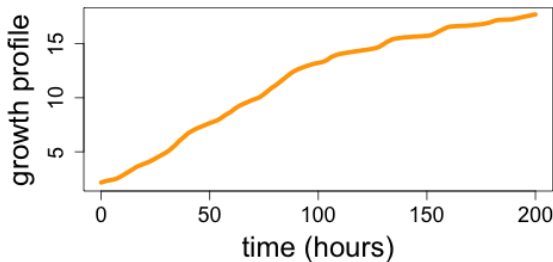
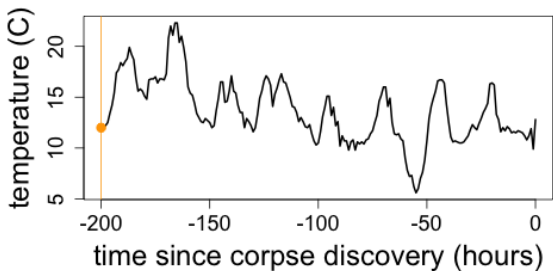
Fine grid of time $0 = t_0 < t_1 < \dots < t_p < t < t_{p+1}$

Estimated dynamic growth model

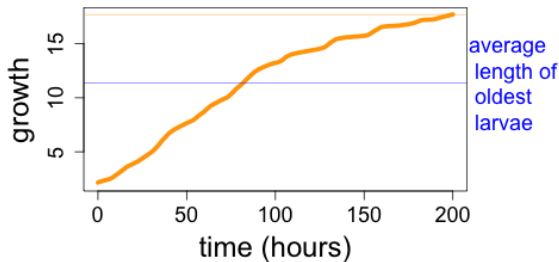
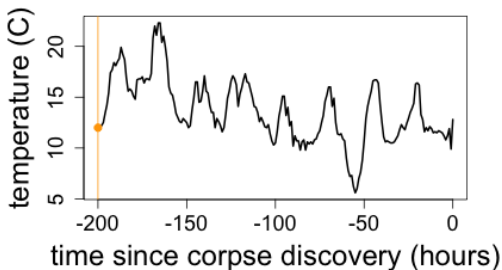
$$\widehat{L}(t_p) - \widehat{L}_{T_1}(t_1) = \sum_{\ell=1}^p (t_{\ell+1} - t_{\ell}) \left\{ \widehat{L}'_{T_{\ell}} \circ \widehat{L}_{T_{\ell}}^{-1} \circ \widehat{L}(t_{\ell}) \right\}$$

($T_{\ell} :=$ temperature at time t_{ℓ})

Step 4 : Estimated varying temp. growth profile



Step 4 : Estimating hatching time



Step 4 : Estimating post-mortem interval (pmi)

Estimation of pmi

$$\widehat{pmi} \approx t^* - \hat{t}_{hatch} + \underbrace{\hat{t}_{hatch} - t_{egg\ laying}}_{entomology}$$

Two forensic cases : ADH vs GPA

ADH = Acc. Degree Hours (current investigator approach)

GPA = Growth Profile Approach

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No external corroboration (such as defendant confession) of the time the body has been abandoned

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↔ compare our **Growth Profile Approach (GPA)** with ADH method currently used

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↔ compare our **Growth Profile Approach (GPA)** with ADH method currently used

↔ gaussian measurement errors provides 95% confidence interval

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Case 1

- $t_{hatch} \in (-371, 0)$ considered reasonable by forensic scientists
- 70 *Calliphora vicina* larvae collected from the body

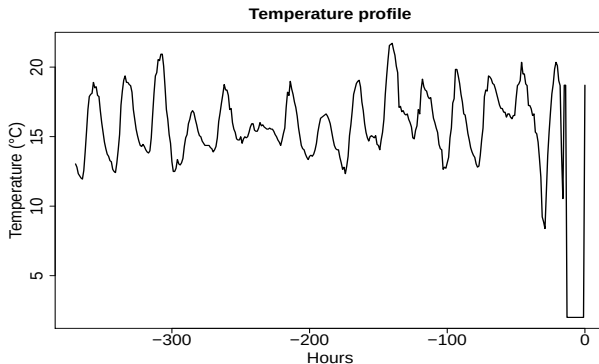
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	ADH	GPA
$\hat{t}_{hatch}$	242 h (10 days)	266 h (11 days)
95% CI (h)	$[-275, -208]$	$[-304, -193]$
95% CI (days)	$[-11.5, -8.7]$	$[-12.7, -8]$

Two forensic cases : ADH vs GPA

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Case 2

- 9 *Calliphora vomitoria* larvae collected from the body
- estimated temp. at crime scene before body discovery

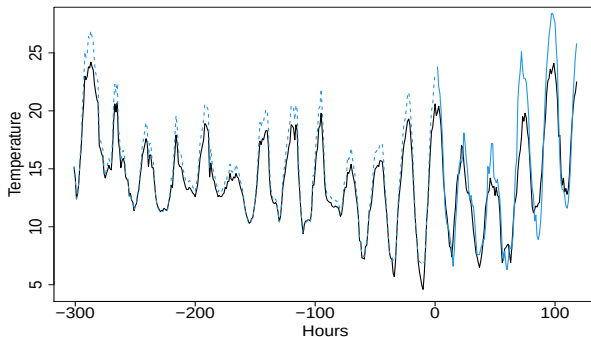
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Case 2

- 9 *Calliphora vomitoria* larvae collected from the body
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	ADH	GPA
$\hat{t}_{hatch}$	255 h (10.6 days)	250 h (10.4 days)
95% CI (h)	$[-270, -240]$	$[-252, -247]$
95% CI (days)	$[-11.2, -10]$	$[-10.5, -10.3]$

Various issues

We need supplementary entomology knowledge

- Is the development of larvae in laboratory the same as those in natural environment?
- larval-generated heat due to high concentration of specimens may have significant effect on developmental rate
- ...

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- ...

We also need further statistical investigations about the distribution of the estimators to assess variability

D. Pigoli, F. Ferraty, J. Aston, A. Mazumder, C. Richards and M. Hall (2023). Estimation of temperature-dependent growth profile for the assessment of time of hatching in Forensic Entomology. *JRSSC* (Accepted).

Thank you for your attention !