Modelling honey bees in winter

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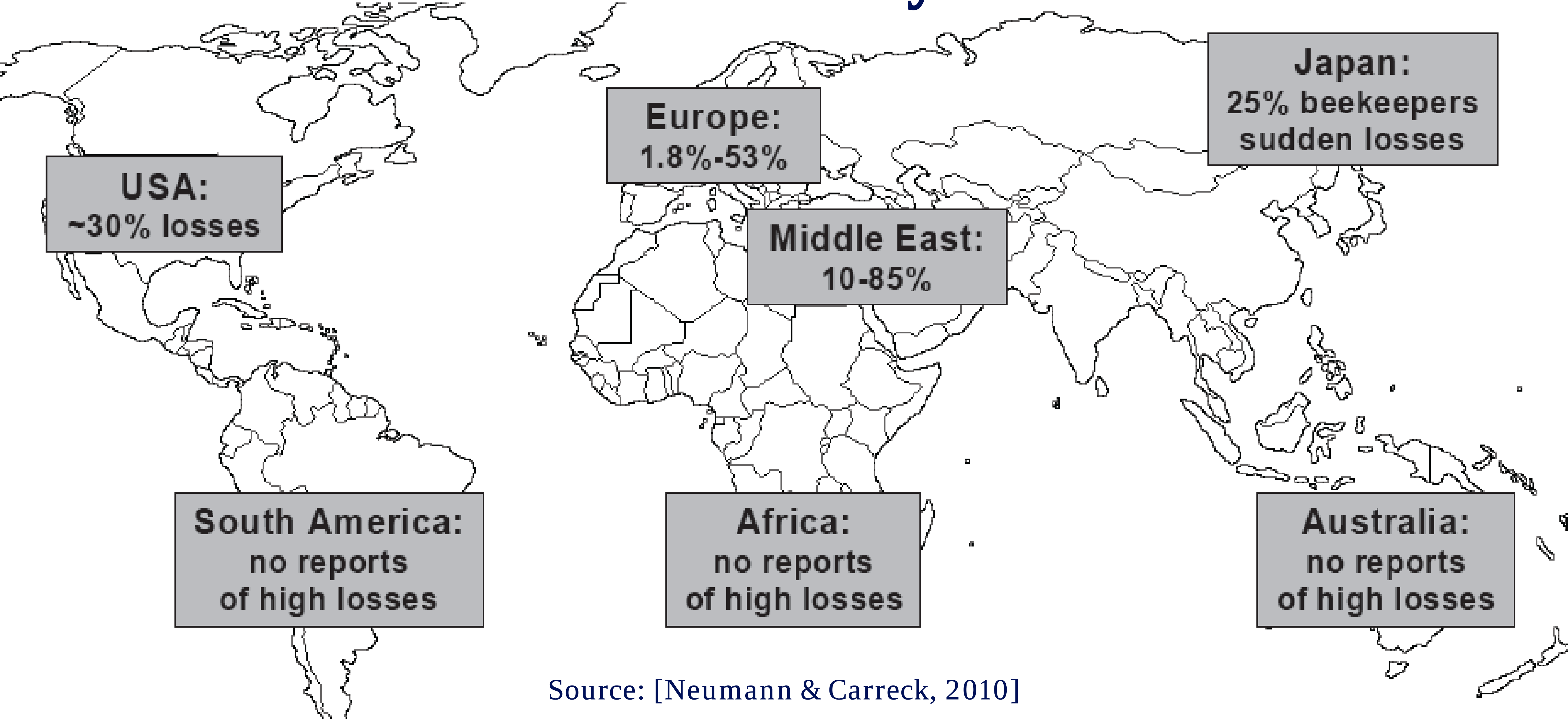
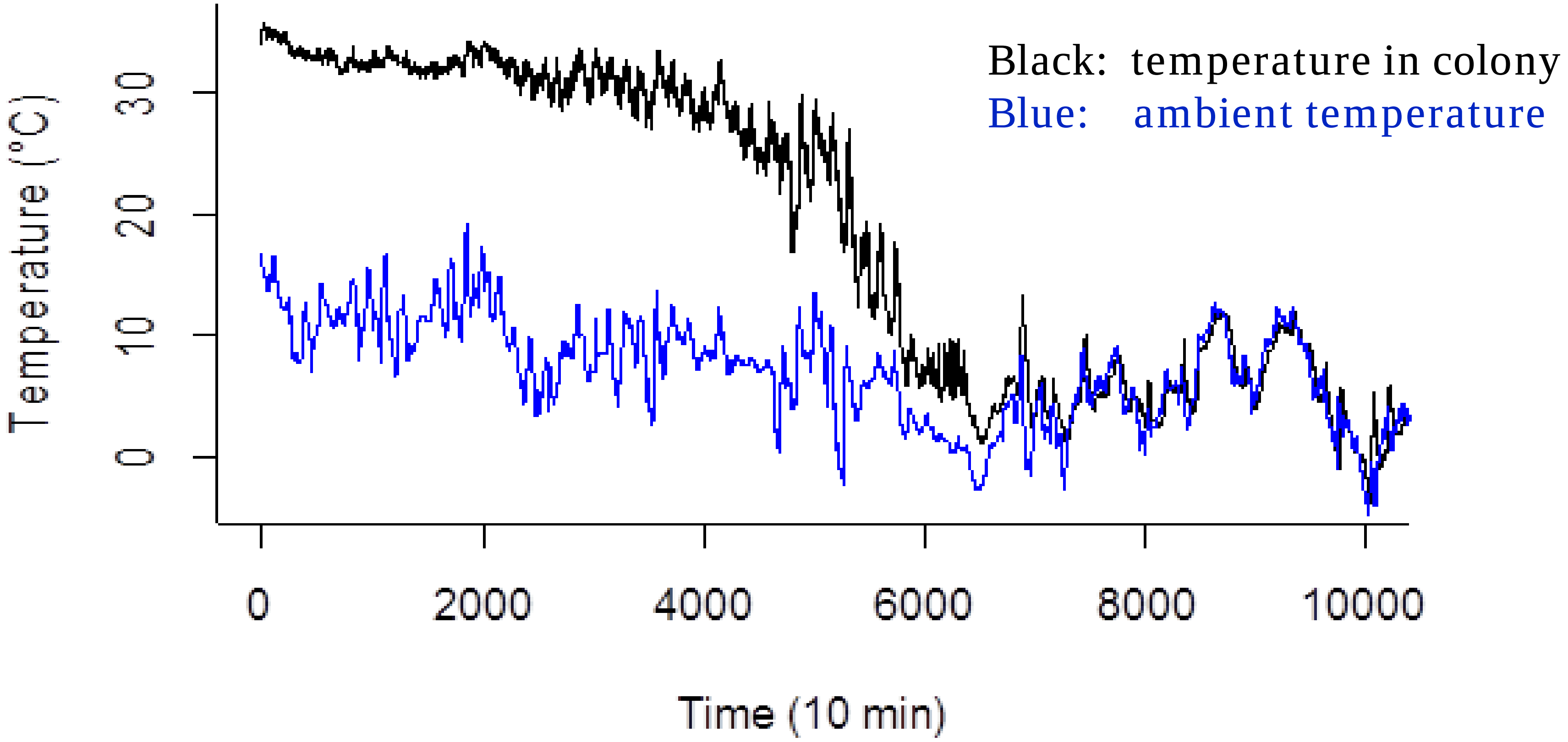
Global losses of honey bee colonies



Source: [Neumann & Carreck, 2010]

Surviving the winter



Key to survive winter: generation & preservation of heat

Thermoregulation in bee colonies

NOT: centralised mechanism

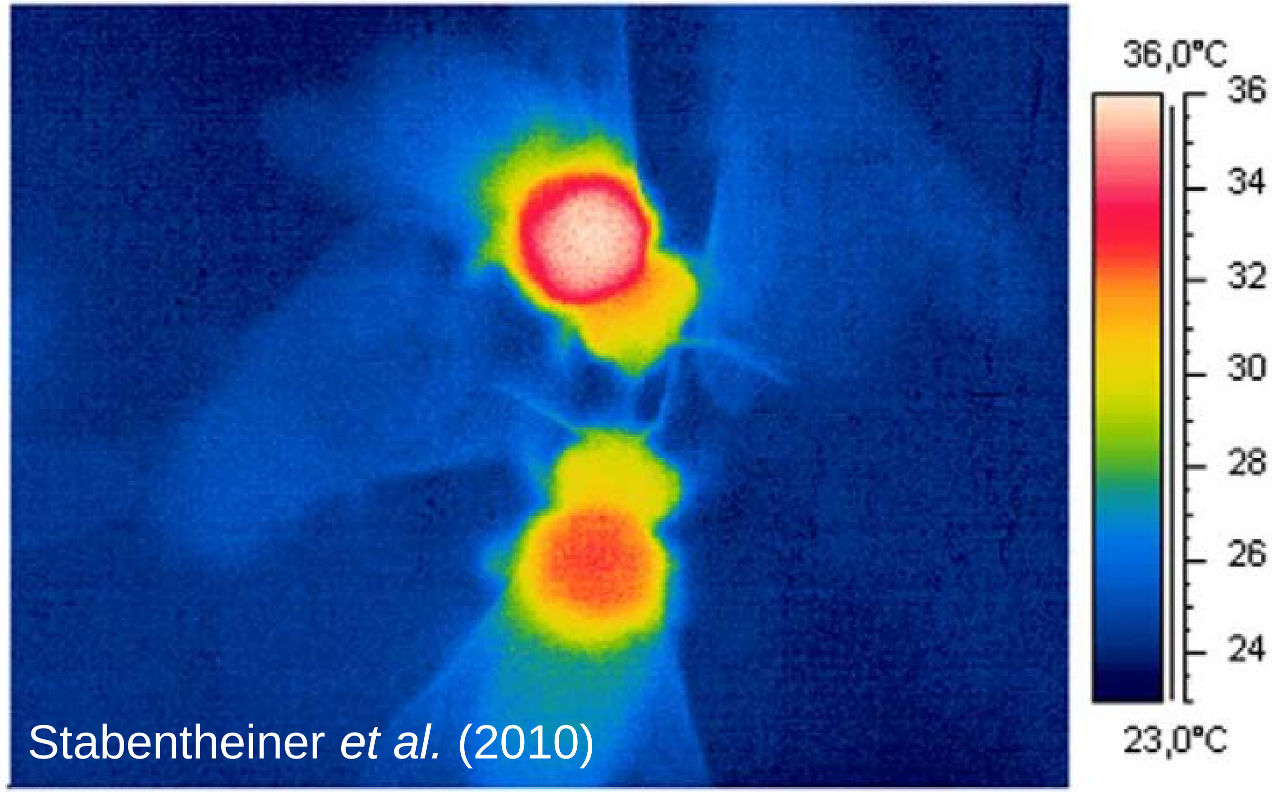
NOT: communication between bees

Thermoregulation is self-organized?

TWO EFFECTS:

→Shivering with flight muscles

→Thermotactic movement



Stabentheiner *et al.* (2010)

Keller-Segel model for honey bees

$$T_t = T_{xx} + f\rho$$
$$\rho_t = [\rho_x - \chi(T)\rho T_x]_x$$

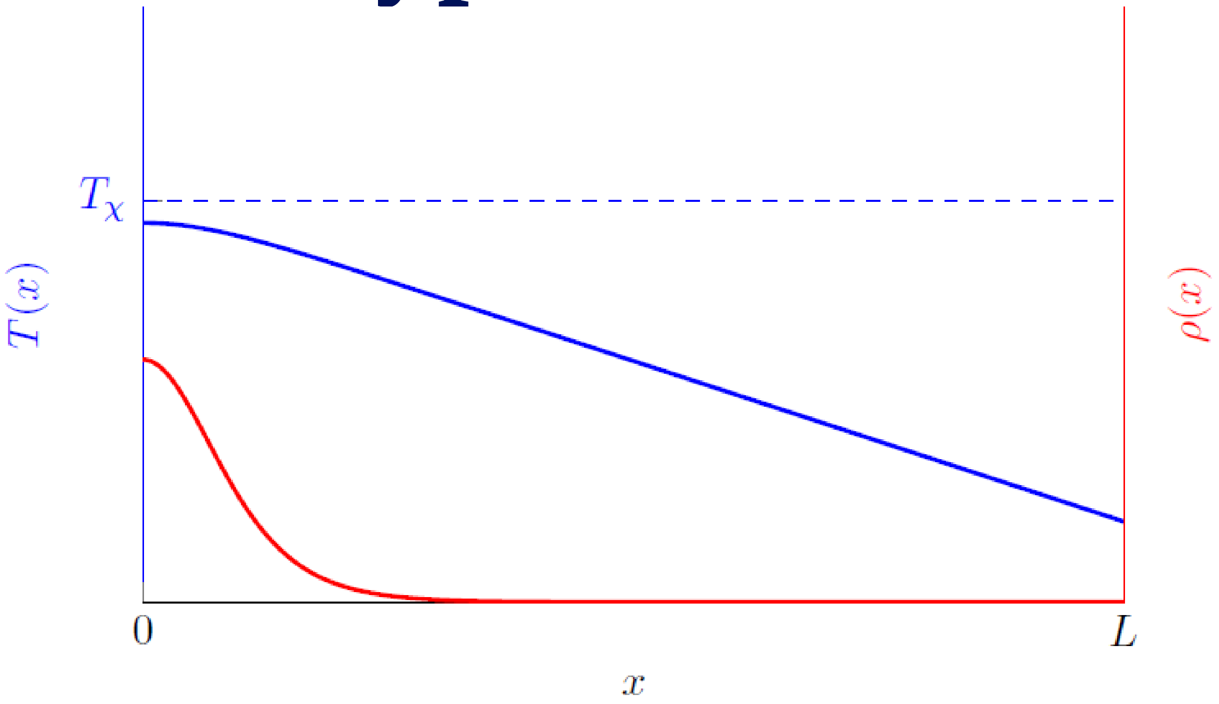
$$\chi(T) = \begin{cases} +\chi_1 & T < T_\chi \\ -\chi_2 & T > T_\chi \end{cases}$$

Boundary Conditions

$x = 0$ (center)	$x = L$ (edge)
$T_x(0) = 0$	$T(L) = T_a$
$\rho_x(0) = 0$	$(\rho_x - \chi(T)\rho T_x)(L) = 0$

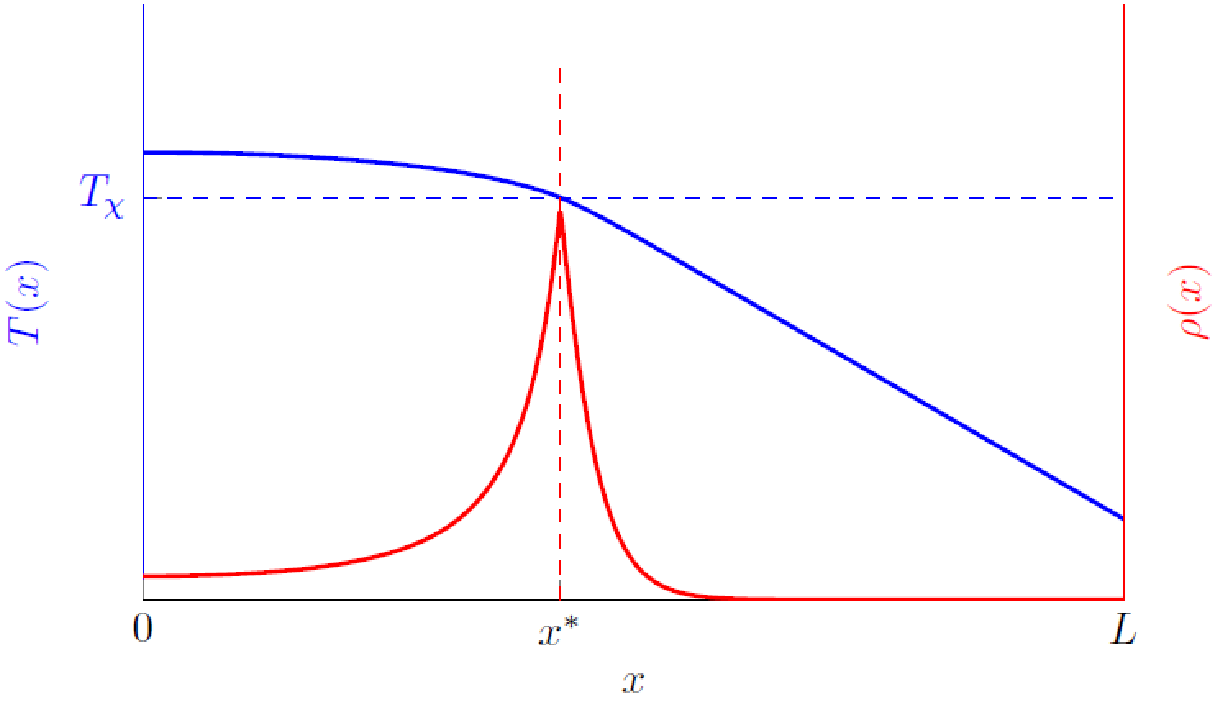
Based on [Watmough & Camazine, 1995]

Two types of stationary states



Type I solution

$$\int_0^L \rho \; dx < \rho_c$$



Type II solution

$$\int_0^L \rho \; dx > \rho_c$$

$$\rho_c := \frac{2}{\bar{f} L \chi_1} \sqrt{1 - \exp\left[-\chi_1 (T_\chi - T_a)\right]} \log\left(\sqrt{\exp\left[\chi_1 (T_\chi - T_a)\right] - 1} + \exp\left[\frac{\chi_1}{2}(T_\chi - T_a)\right] \right)$$

Mortality (1)

$$T_t = T_{xx} + f\rho$$

$$\rho_t = [\rho_x - \chi(T)\rho T_x]_x - \theta(\rho, T)\rho$$

Mortality is influenced by the amount of work a bee has to perform

$$\theta(\rho, T) = \theta_0\, \theta_T(T)\, \theta_D(\rho)\, \theta_m(\rho)$$

Local temperature → $\theta_T(T)$

Refresh rates → $\theta_D(\rho)$

Mites → $\theta_m(\rho)$

Mortality (2)

$$\theta(\rho, T) = \theta_0\ \theta_T(T)\ \theta_D(\rho)\ \theta_m(\rho)$$

Temperature effect:

$$\theta_T(T) = \begin{cases} 1 & T < T_\theta \\ 0 & T > T_\theta \end{cases}$$

Refresh rate effect:

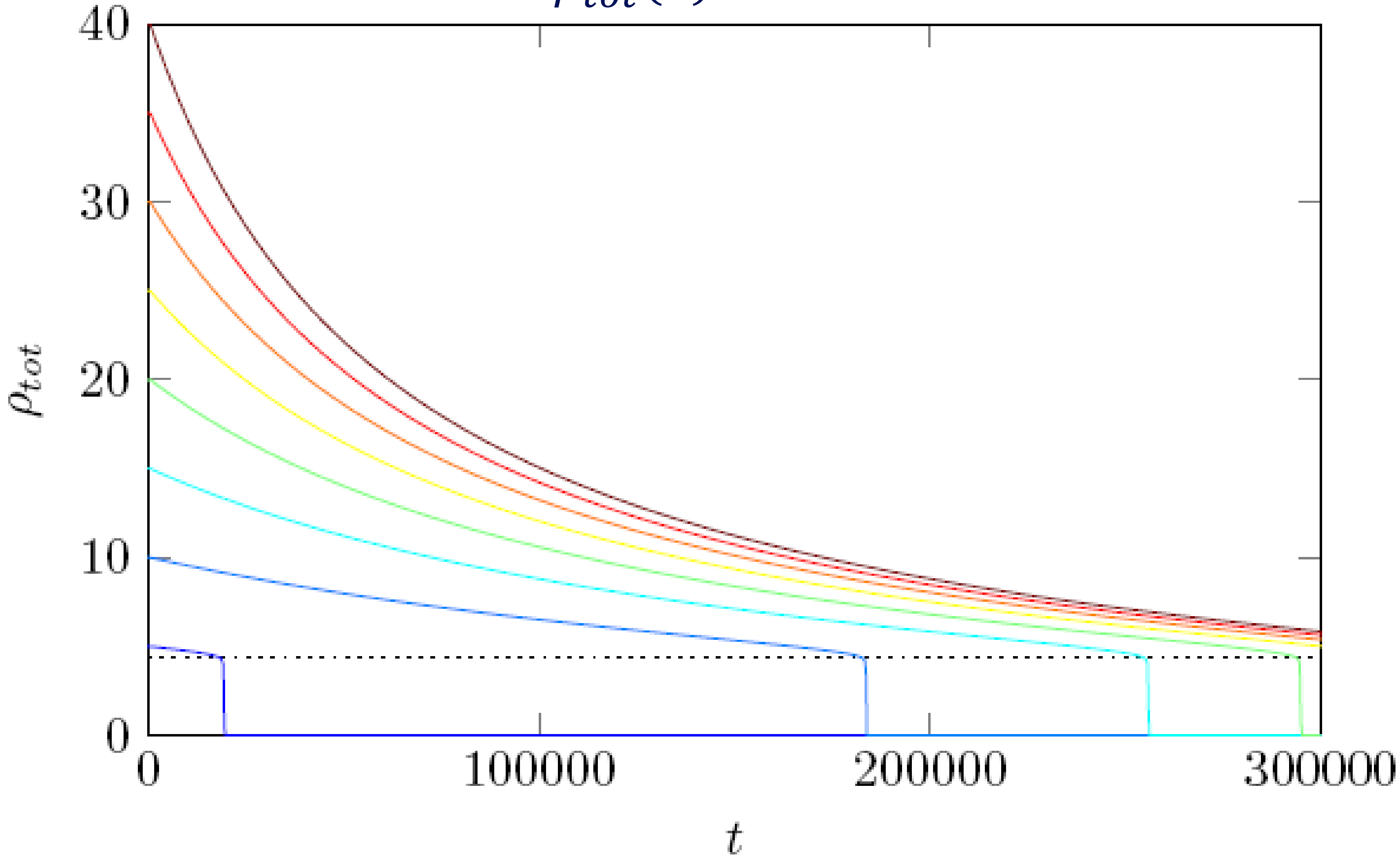
$$\theta_D(\rho) = \frac{\rho}{\rho_{tot}^{\gamma}}$$

Effect of mites:

$$\theta_m(\rho) = 1 + \frac{m}{\rho_{tot}}$$

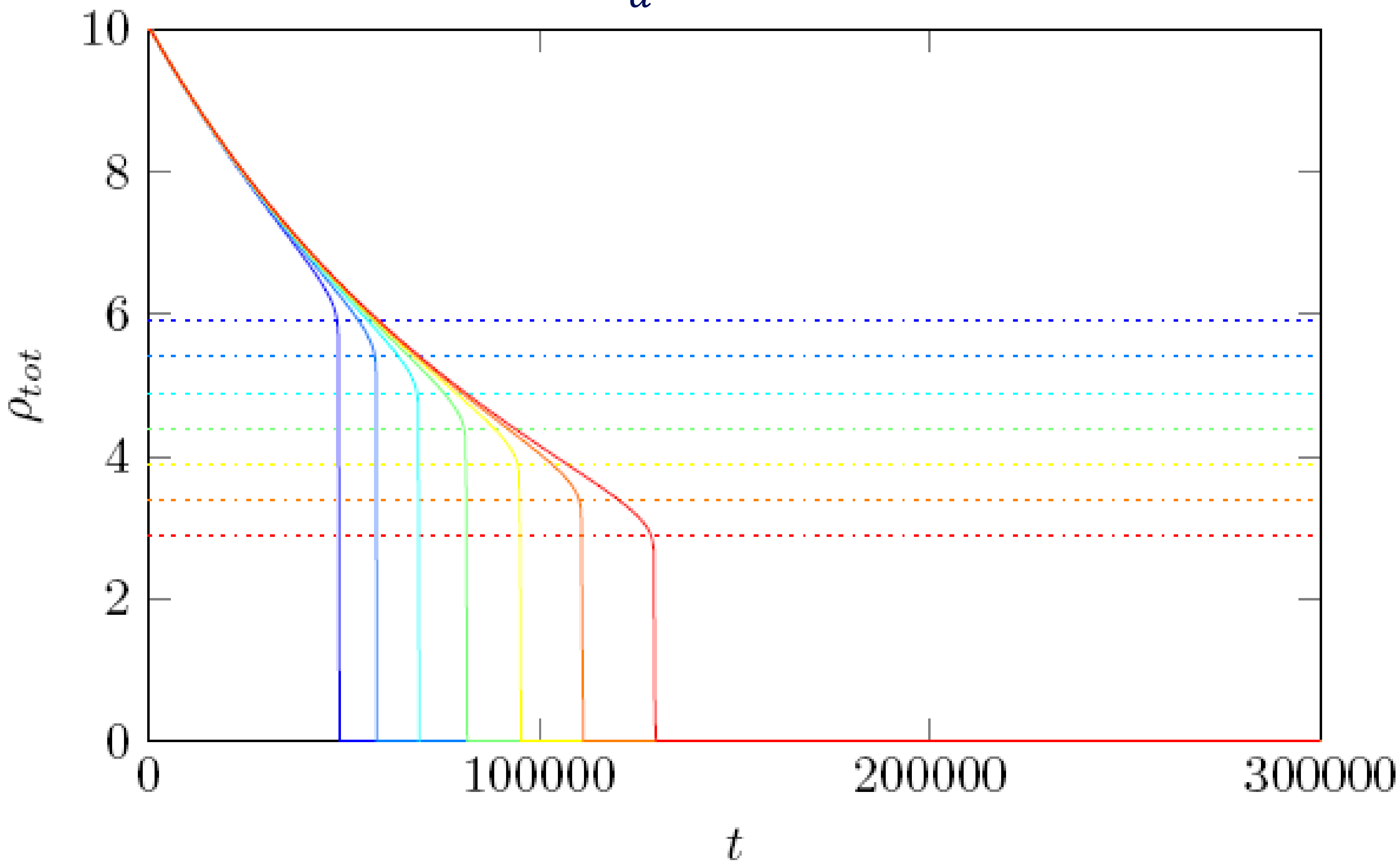
Simulation results (1)

$\rho_{tot}(0)$ varies

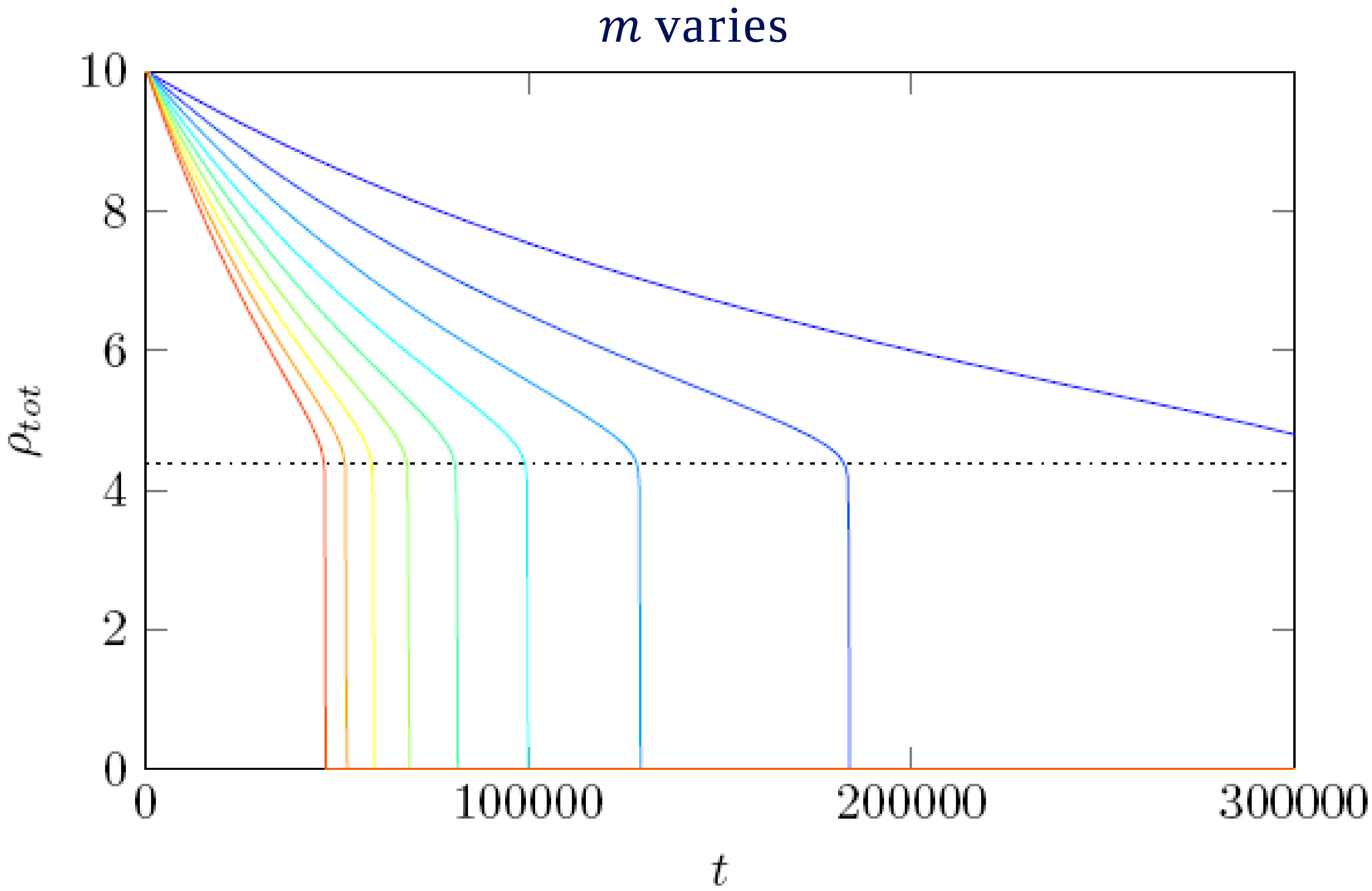


Simulation results (2)

T_a varies



Simulation results (3)



Conclusions

Bees die in winter because of failed self-organised thermoregulation

- Enough bees are needed to warm a colony
- More bees are needed for this in colder period
- Bee deaths influenced by bee work load