FRIEDRICH-LOEFFLER-INSTITUT
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Insects and Climate

A short guide to model insect populations dynamics

Motivation

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Due to global warming tropical insect populations are at risk to extinct. US scientists argue that insect populations inhabiting tropical regions are very well adapted to the temperatures in these regions and slight changes of temperature may lead to extinction.

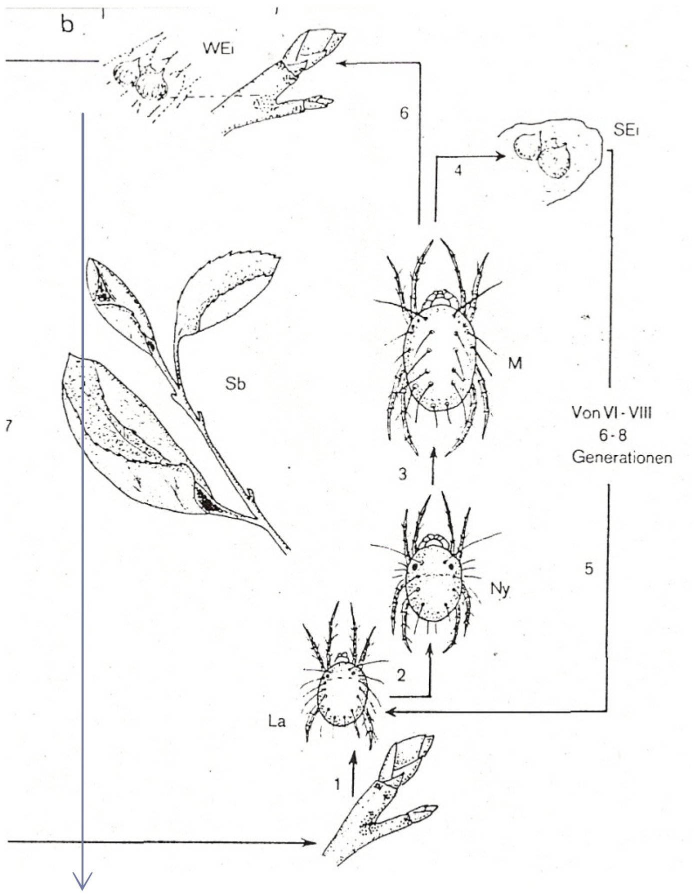
Contents

- Insects
  - The model
  - Aspects of the lifecycle
    - Development
    - Lifetime
    - Fecundity
- Insect population dynamics and global warming

The Model

Insects lifecycle

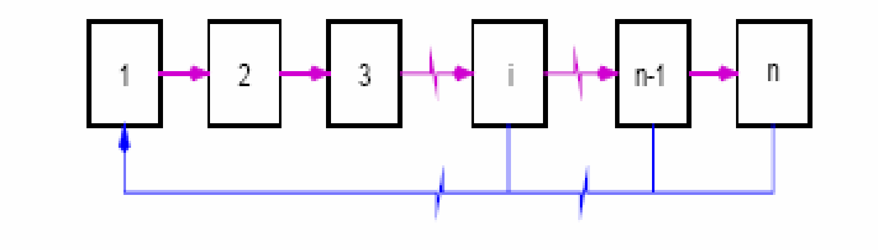
The model



Insect lifecycle

simple

Biological processes are age specific



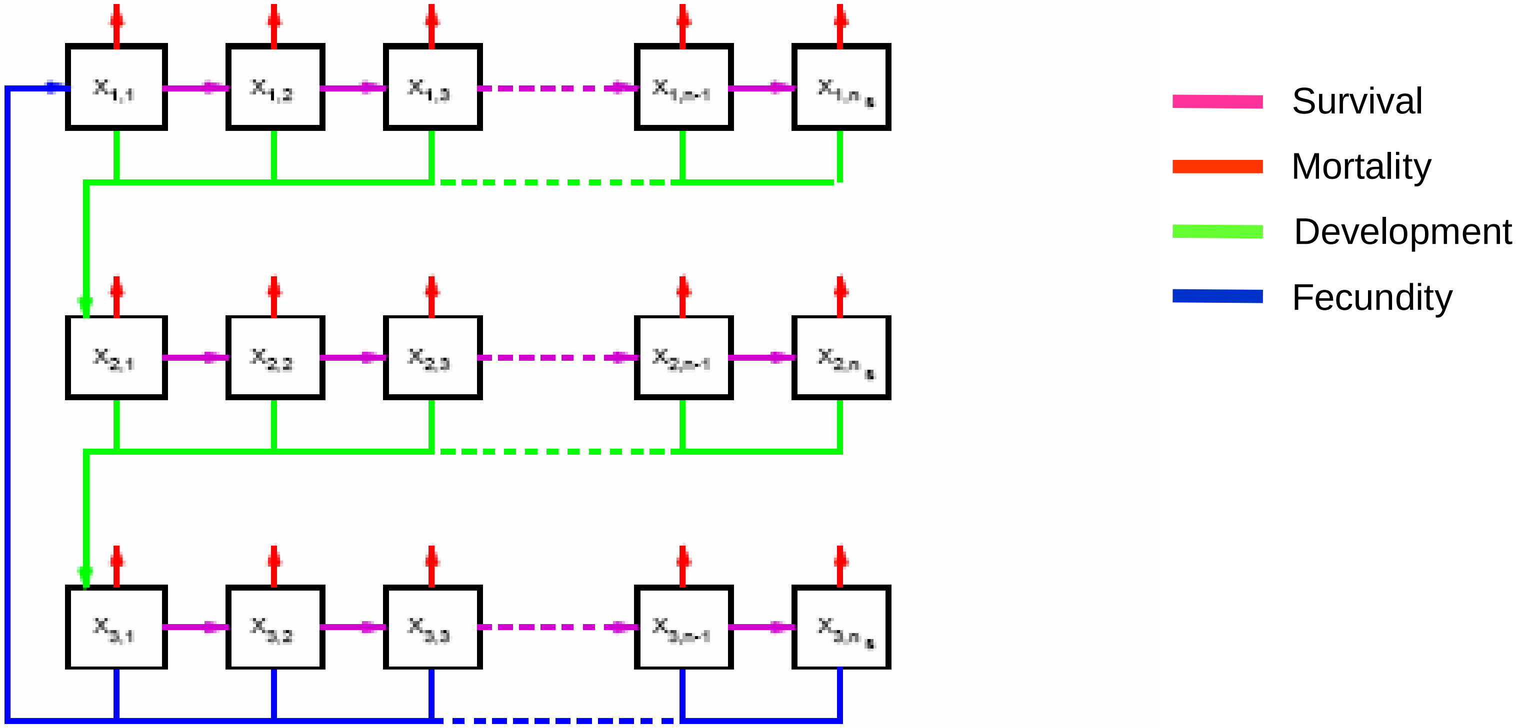
$$\begin{aligned} x_{i+1}(t+1) &= P(i)\, x_i(t) \qquad i = 1, \dots, n-1, \\ x_1(t+1) &= \sum_{i=1}^{n} F(i)\, x_i(t), \end{aligned}$$

$$\mathbf{X}(t+1) = \mathbf{A}\, \mathbf{X}(t).$$

$$\mathbf{A} = \begin{bmatrix} F(1) & F(2) & F(3) & \dots & F(n-1) & F(n) \\ P(1) & 0 & 0 & \dots & 0 & 0 \\ 0 & P(2) & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & 0 & \dots & P(n-1) & 0 \end{bmatrix}$$

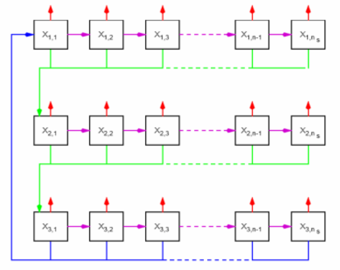
Insects Lifecycle

complex



Insect lifecycle

complex



$$\begin{aligned}
x_{s,i+1}(t+1) &= P_s(i)\,(1-U_s(i))\,x_{s,i}(t) \\
x_{s+1,1}(t+1) &= \sum_{i=1}^{n} U_s(i)\,x_{s,i}(t) \\
x_{1,1}(t+1) &= \sum_{i=1}^{n} F(i)x_{s,i}(t) \\
\text{mit} \quad & U_s() = 0 \text{ für } s = m.
\end{aligned}$$

Insect Lifecycle

complex

$$\mathbf{A} = \left[\begin{array}{ccc|ccc|ccc}
0 & 0 & 0 & 0 & 0 & 0 & F_3(1) & F_3(2) & F_3(3) \\
\widetilde{P_1(1)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \widetilde{P_1(2)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
U_1(1) & U_1(2) & U_1(3) & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \widetilde{P_2(1)} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \widetilde{P_2(2)} & 0 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & U_2(1) & U_2(2) & U_2(3) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & P_3(1) & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & P_3(2) & 0
\end{array}\right],$$

mit $\widetilde{P_s(i)} = P_s(i)(1 - U_s(i))$ für $s < m$.

$$\mathbf{A} = \left[\begin{array}{c|c|c}
\mathbf{P_1} & \mathbf{0} & \mathbf{F_3} \\
\hline
\mathbf{U_1} & \mathbf{P_2} & \mathbf{0} \\
\hline
\mathbf{0} & \mathbf{U_2} & \mathbf{P_3}
\end{array}\right].$$

Insects lifecycle

Matrix characteristics

- A is a non-negative quadratic matrix
  - Eigenvalues and left and right eigenvectors can be calculated
  - Sensitivity and Elasticity analysis can be performed (Caswell, 2001)

Aspects of the insect lifecycles

- Aspects are:
  - Development
  - Survival
  - Fecundity
- Depend on temperature (humidity, rainfall, …)

Aspects of insects’ lifecycles

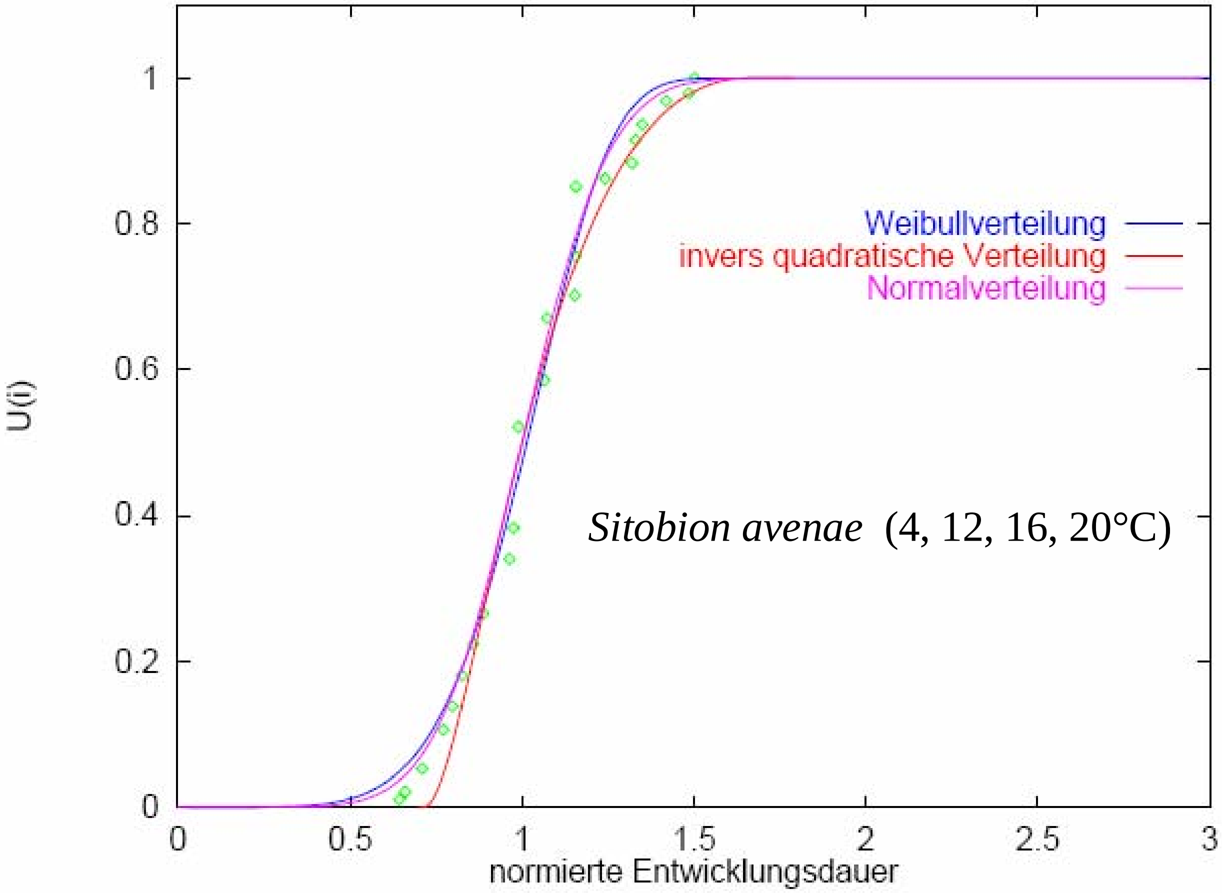
Aspects of insect lifecycles

Development

- Development
    - Development varies between individual
    - Mean development time depends on temperature

Aspects of insect lifecycles
Development

Individual variation



Aspects of insect lifecycles

Development

Temperature effect on mean development rate

The Hilber&Logan model (1982)

$$r(T) = \psi\left(\frac{T^2}{T^2 + D^2} - \exp(-(T_m - T)/\Delta T)\right)$$

$$T = T_o - T_b$$

T_o	Lufttemperatur [°C]
T_b	Temperaturschwelle [°C] für die Entwicklung
T_m	Letaltemperatur [°C]
D	Formparameter
ΔT	Breite des Temperaturfensters oberhalb der Optimaltemperatur

Aspects of insect lifecycles

Development

Temperature effect on mean development rate

The O’Neill model (1972)

$$r(T) \quad = \quad R_{max}\left(\frac{T_m - T}{T_m - T_{opt}}\right)^a \exp\left(\frac{a(T - T_{opt})}{T_m - T_{opt}}\right)$$

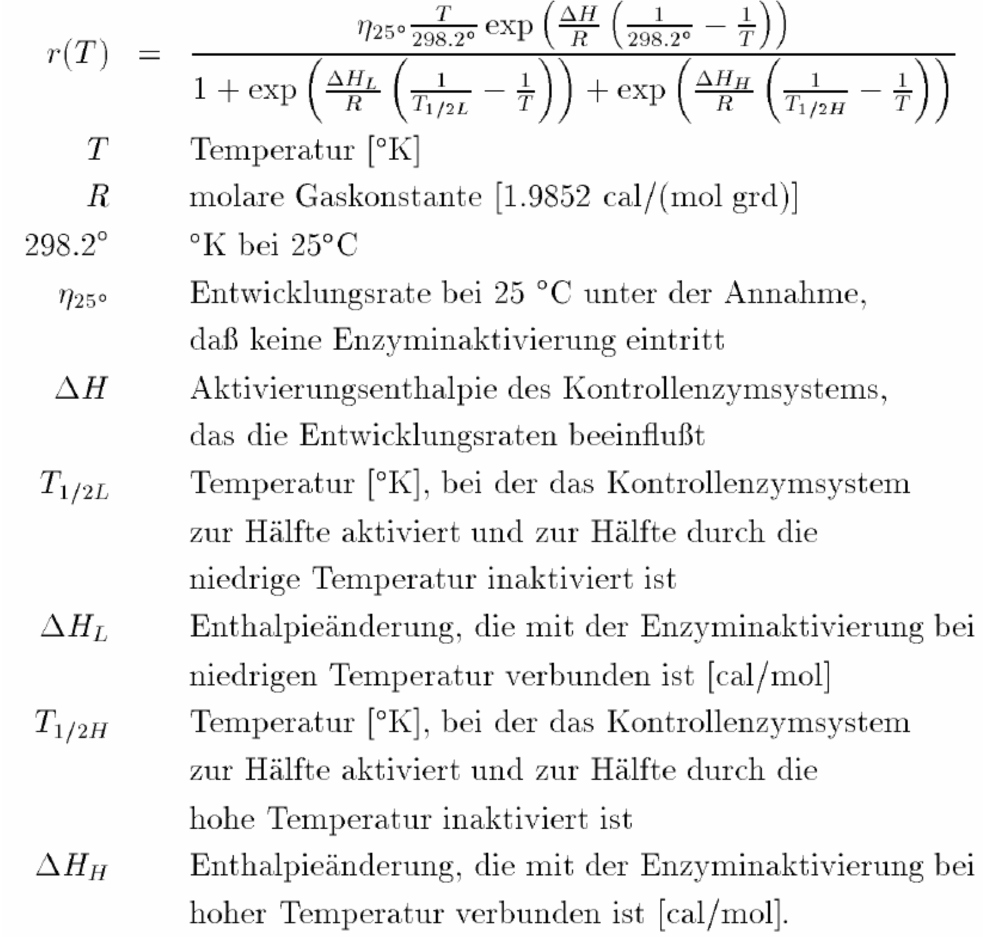
R_{max}	Entwicklungsrate bei Optimaltemperatur [°C]
T_m	Letaltemperatur [°C]
T_{opt}	Optimaltemperatur[°C]
a	Formparameter

Aspects of insect lifecycles

Development

Temperature effect on mean development rate

The Schoolfield model (1981)

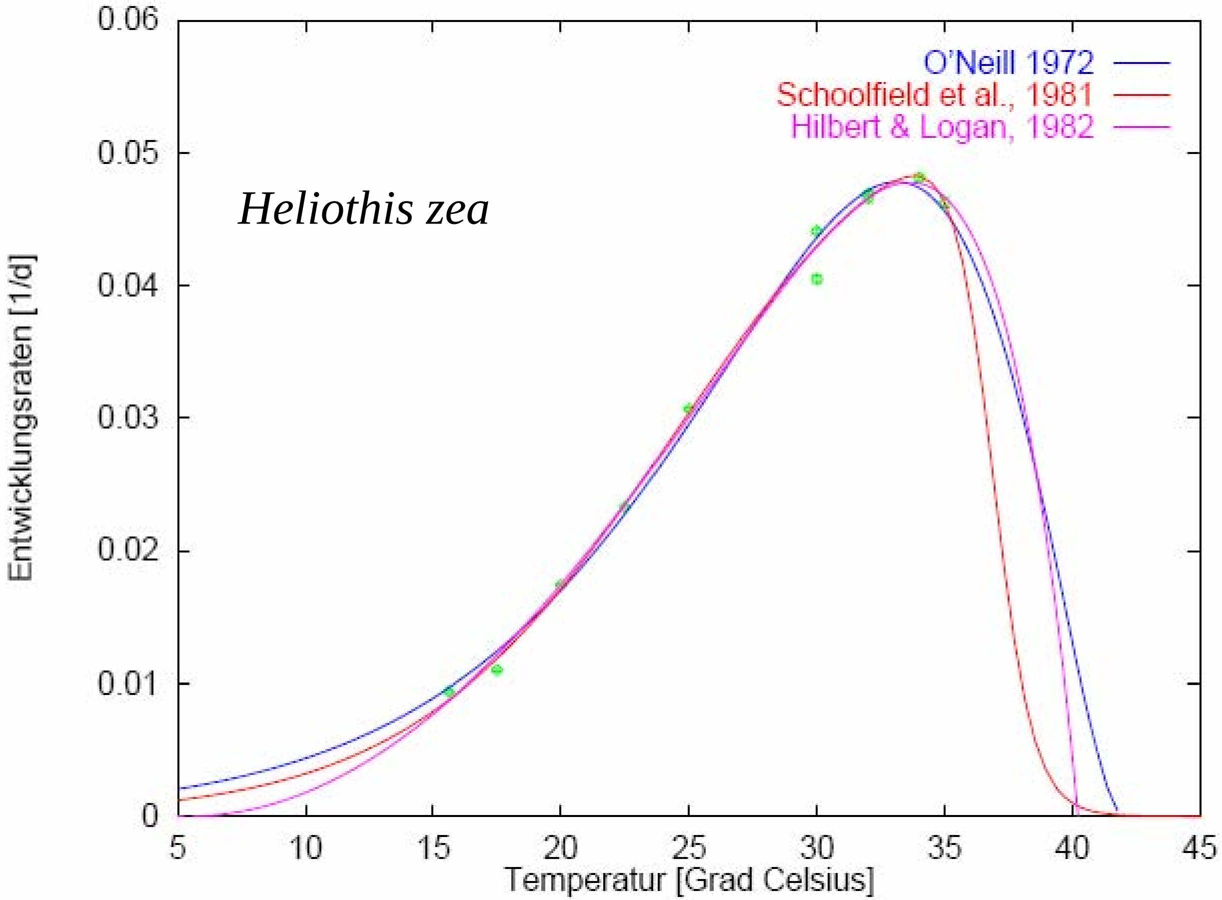


$$r(T) = \frac{\eta_{25^\circ}\frac{T}{298.2^\circ}\exp\left(\frac{\Delta H}{R}\left(\frac{1}{298.2^\circ}-\frac{1}{T}\right)\right)}{1+\exp\left(\frac{\Delta H_L}{R}\left(\frac{1}{T_{1/2L}}-\frac{1}{T}\right)\right)+\exp\left(\frac{\Delta H_H}{R}\left(\frac{1}{T_{1/2H}}-\frac{1}{T}\right)\right)}$$

T	Temperatur [°K]
R	molare Gaskonstante [1.9852 cal/(mol grd)]
298.2°	°K bei 25°C
η_{25°	Entwicklungsrate bei 25 °C unter der Annahme, daß keine Enzyminaktivierung eintritt
ΔH	Aktivierungsenthalpie des Kontrollenzymsystems, das die Entwicklungsraten beeinflußt
$T_{1/2L}$	Temperatur [°K], bei der das Kontrollenzymsystem zur Hälfte aktiviert und zur Hälfte durch die niedrige Temperatur inaktiviert ist
ΔH_L	Enthalpieänderung, die mit der Enzyminaktivierung bei niedrigen Temperatur verbunden ist [cal/mol]
$T_{1/2H}$	Temperatur [°K], bei der das Kontrollenzymsystem zur Hälfte aktiviert und zur Hälfte durch die hohe Temperatur inaktiviert ist
ΔH_H	Enthalpieänderung, die mit der Enzyminaktivierung bei hoher Temperatur verbunden ist [cal/mol].
]

Aspects of insect lifecycles

Development



(Data Sharpe, 1981)

Aspects of insect lifecycles

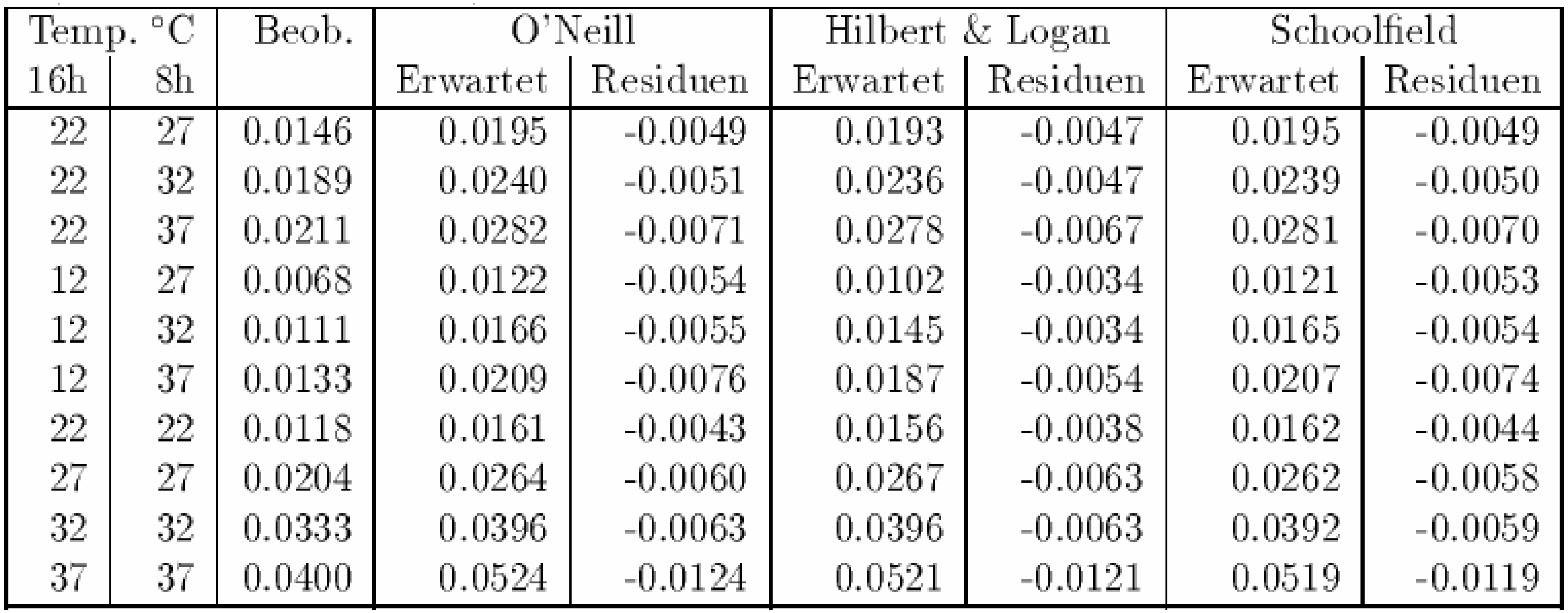
Development

- Constant temperature experiments are not suited to predict insect development under fluctuating temperatures

Aspects of insect lifecycles

Development

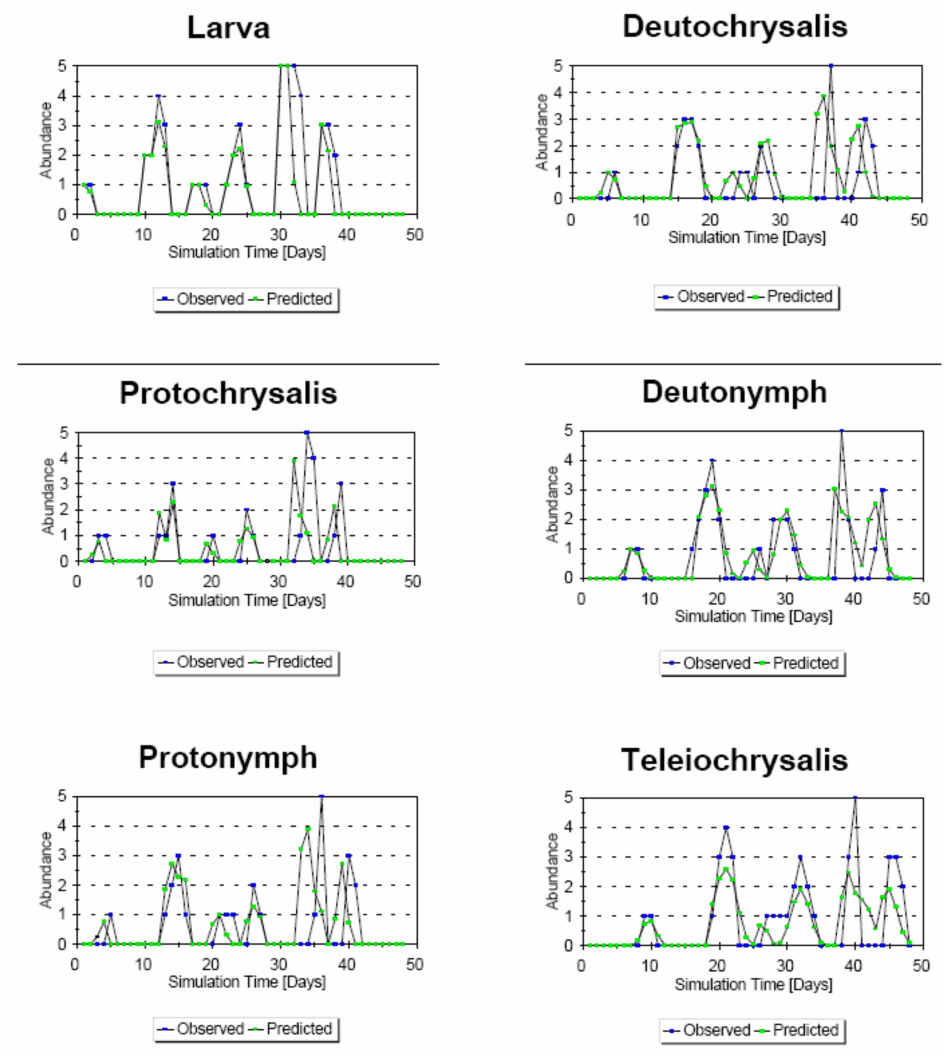
Fluctuating temperature experiments



Temp. °C		Beob.	O'Neill		Hilbert & Logan		Schoolfield	
16h	8h		Erwartet	Residuen	Erwartet	Residuen	Erwartet	Residuen
22	27	0.0146	0.0195	-0.0049	0.0193	-0.0047	0.0195	-0.0049
22	32	0.0189	0.0240	-0.0051	0.0236	-0.0047	0.0239	-0.0050
22	37	0.0211	0.0282	-0.0071	0.0278	-0.0067	0.0281	-0.0070
12	27	0.0068	0.0122	-0.0054	0.0102	-0.0034	0.0121	-0.0053
12	32	0.0111	0.0166	-0.0055	0.0145	-0.0034	0.0165	-0.0054
12	37	0.0133	0.0209	-0.0076	0.0187	-0.0054	0.0207	-0.0074
22	22	0.0118	0.0161	-0.0043	0.0156	-0.0038	0.0162	-0.0044
27	27	0.0204	0.0264	-0.0060	0.0267	-0.0063	0.0262	-0.0058
32	32	0.0333	0.0396	-0.0063	0.0396	-0.0063	0.0392	-0.0059
37	37	0.0400	0.0524	-0.0124	0.0521	-0.0121	0.0519	-0.0119

Aspects of insect lifecycles

Development



Selhorst & Soballa, 1995

Aspects of insect lifecycles

Survival

- Survival
  - Lifetime distribution functions to be used
    - Exponential
    - Weibull
    - Gompertz

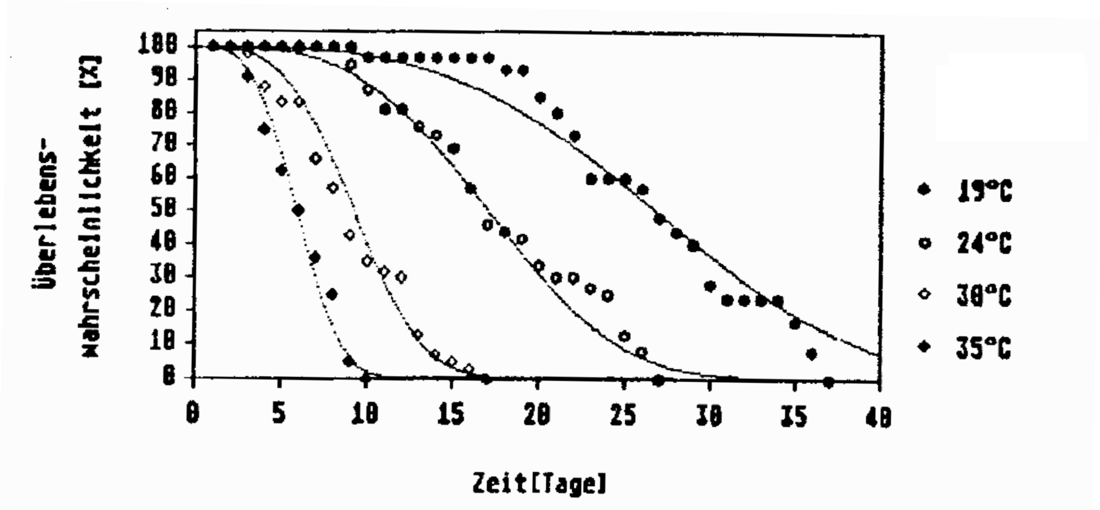
Aspects of insect lifecycles

Survival

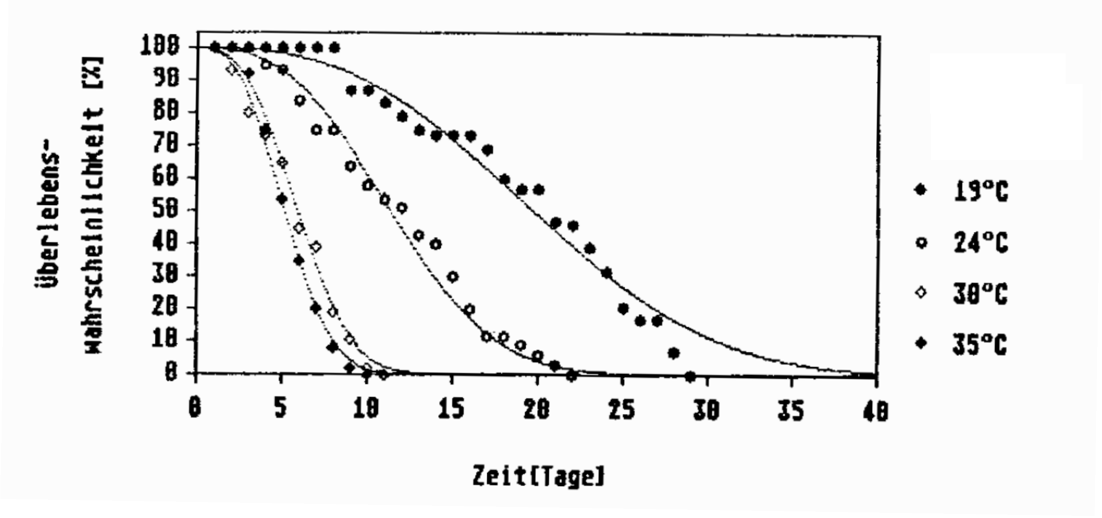
$$\begin{aligned}
l(x) &= 1 - \exp\left(-\left(\frac{x}{E(X)}\right)^{\beta}\right)\\
E(X) &= x_c\,\Gamma(1 + 1/\beta)\\
\Gamma(\cdot) & \quad \text{Gammafunktion.}
\end{aligned}$$

Aspects of insect lifecycles

Survival



38% r.H.

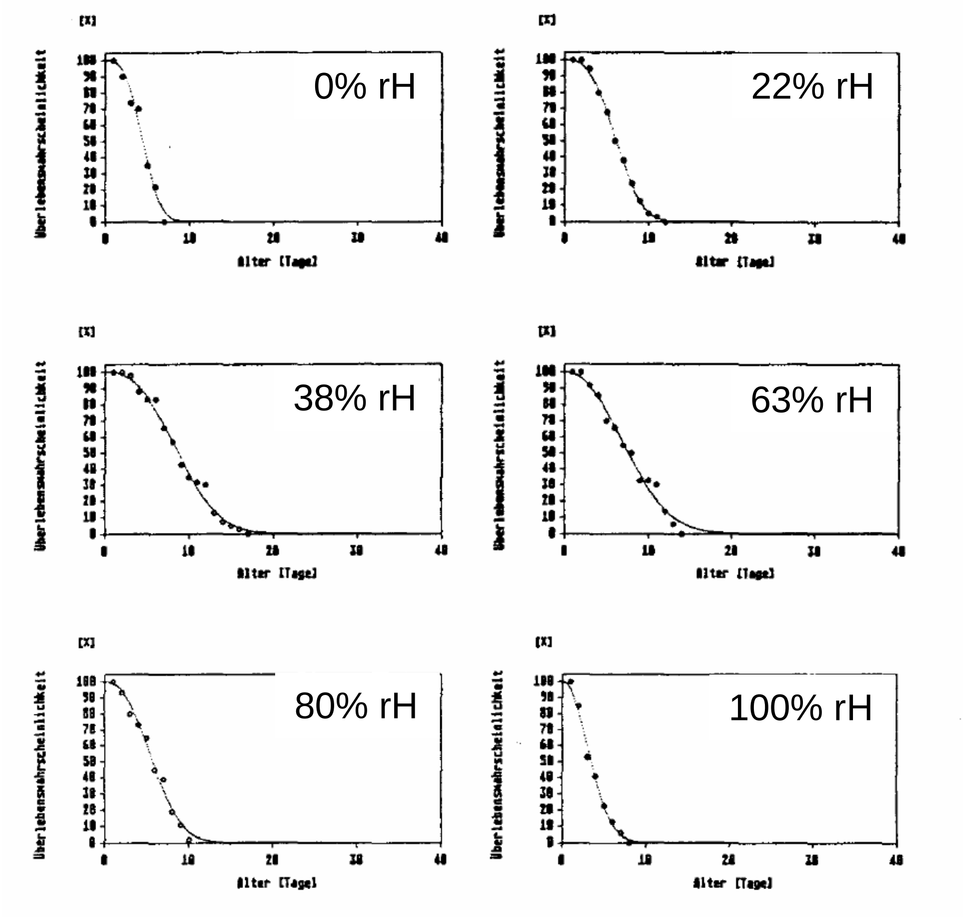


80% r.H.

Aspects of insect lifecycles

Survival

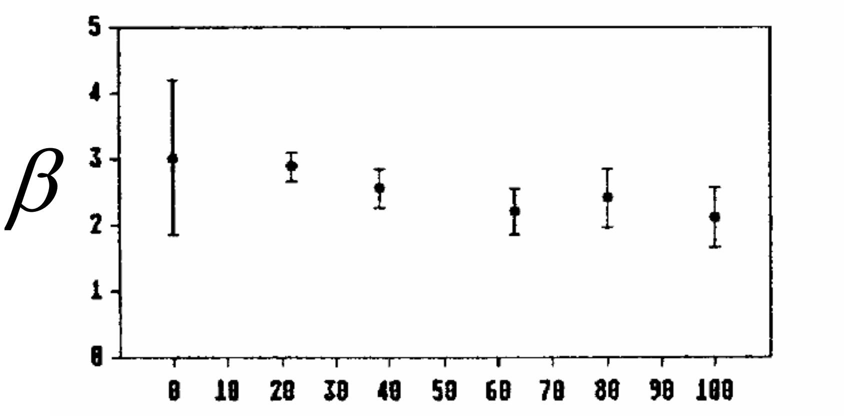
Tetranychus cinnabarinus Boisd. Data: Hazan, 1973

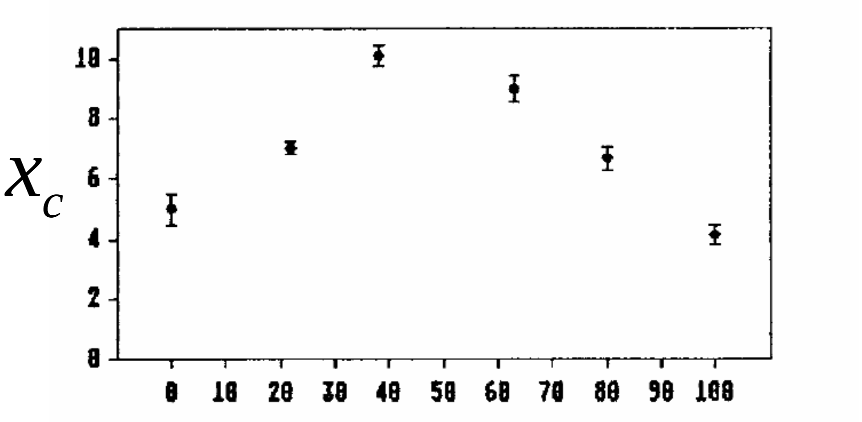


Aspects of insect lifecycles

Survival

$$
\begin{aligned}
l(x) &= 1 - \exp\left(-\left(\frac{x}{E(X)}\right)^{\beta}\right) \\
E(X) &= x_c\,\Gamma(1 + 1/\beta) \\
\Gamma(\cdot) & \quad \textit{Gammafunktion.}
\end{aligned}
$$



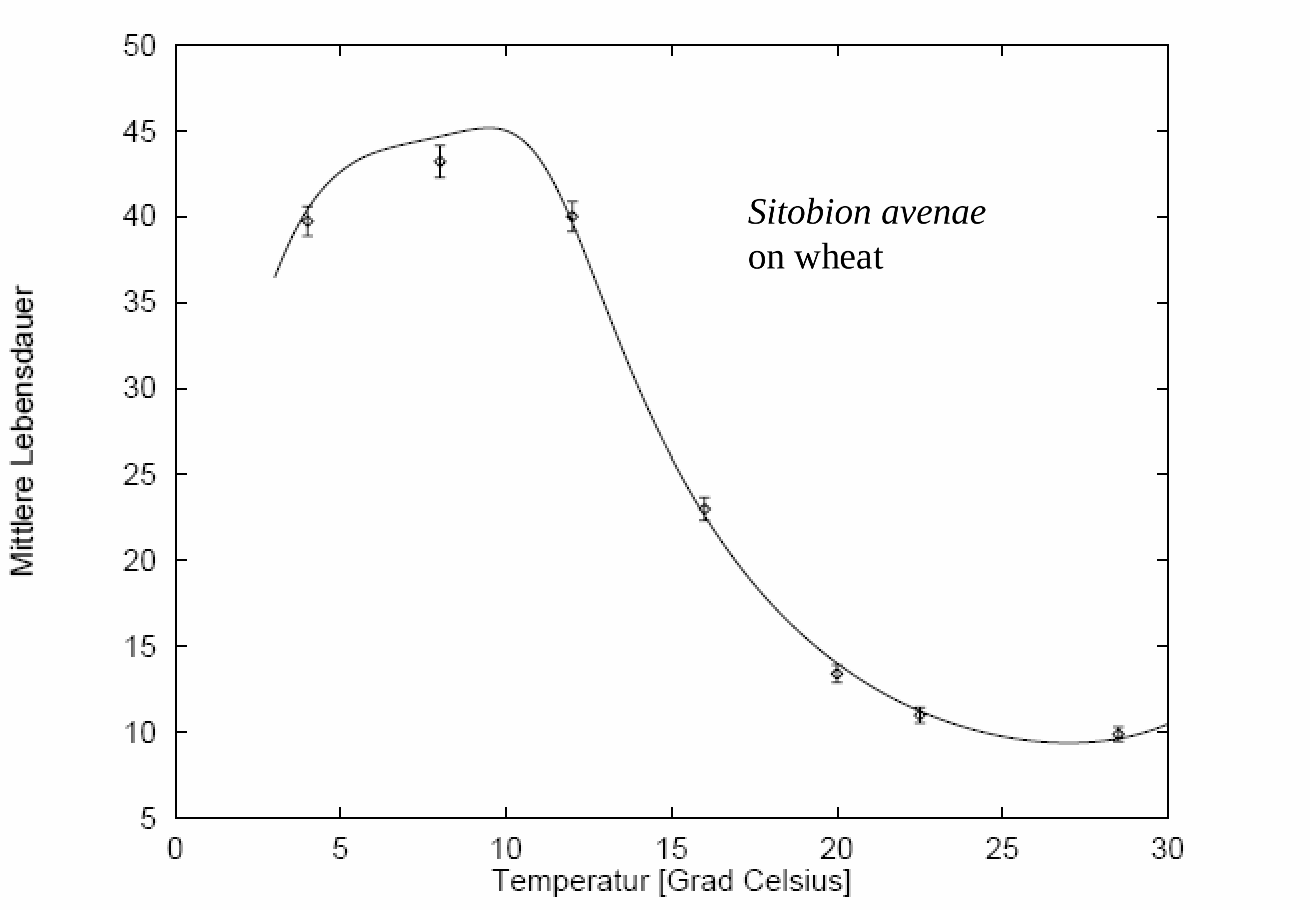


Relative Humidity [%]

Aspects of insect lifecycles

Survival

Extreme Temperature effects

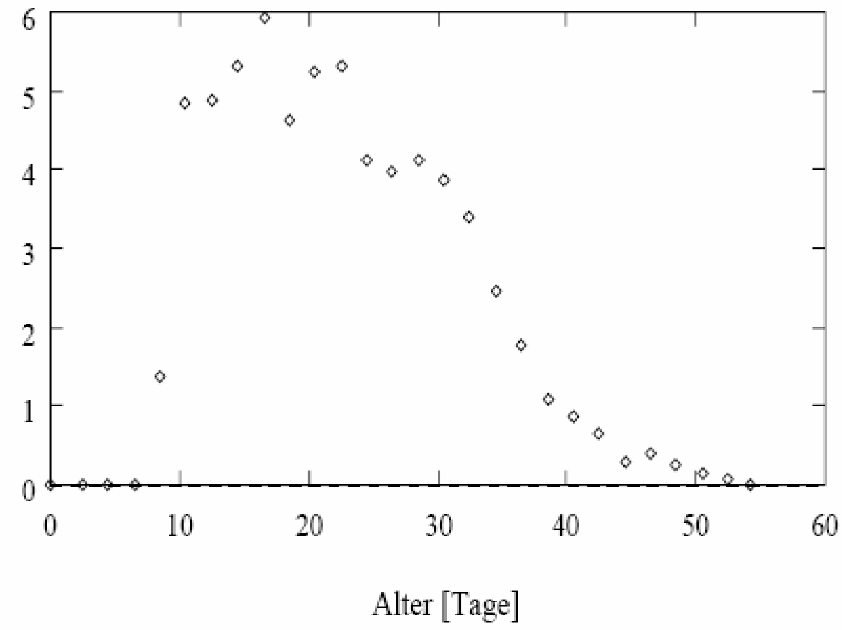


Kleinhenz, Selhorst & Sengonca, 1993

Aspects of insect lifecycles

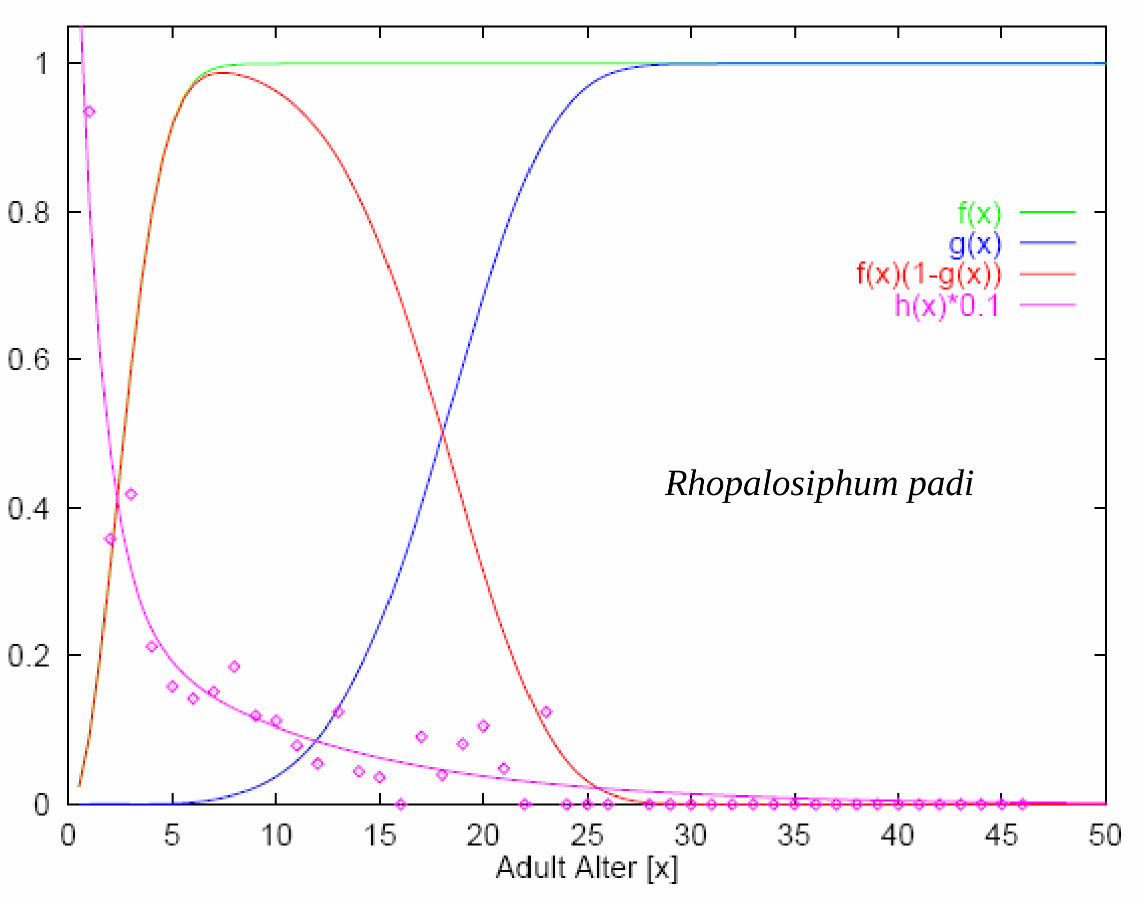
Fecundity

- Fecundity obeys 3 processes
  - Preoviposition period
  - Oviposition period
  - Post oviposition period



Aspects of insect lifecycles

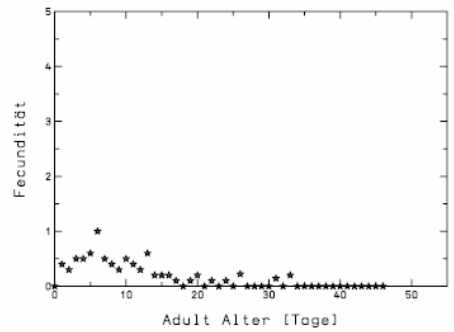
Fecundity



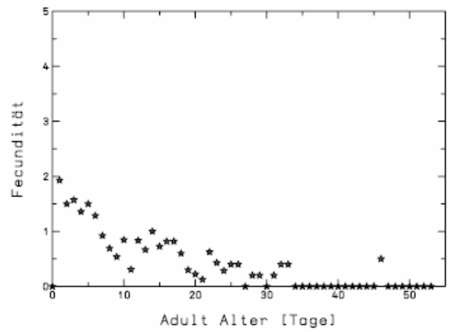
Rhopalosiphum padi

Aspects of insect lifecycles

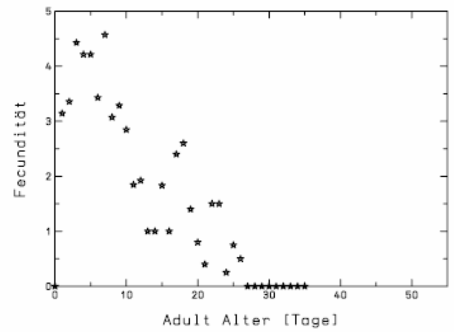
Fecundity



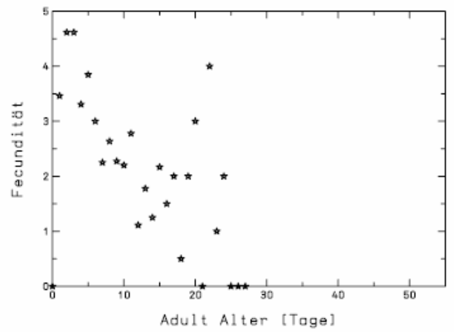
(a) 8°C



(b) 12°C



(c) 16°C



(d) 20°C

Aspects of insect lifecycles

Fecundity

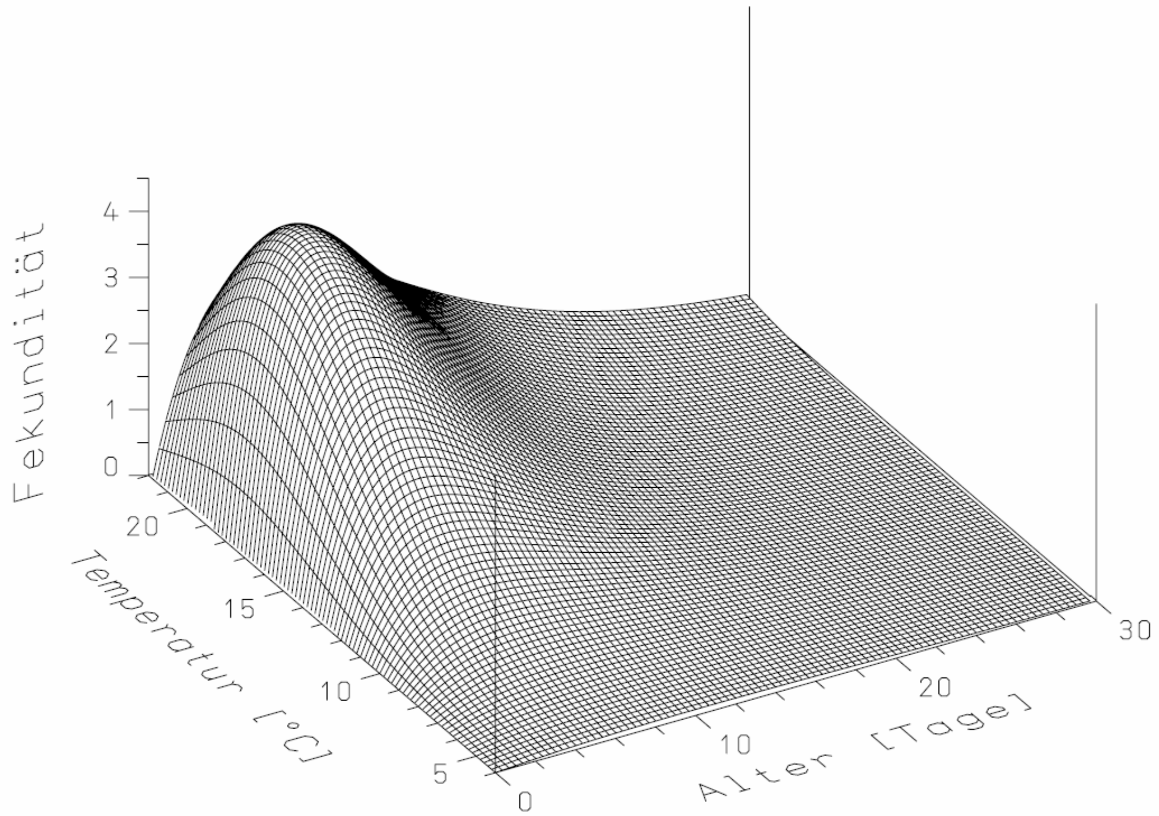
$$y = y^\star x \exp\left(\frac{x^\star - x}{x^\star}\right)\frac{1}{x^\star}.$$

$$\begin{aligned} x^\star &= h(T) \\ y^\star &= g(T) \\ y &= g(T)x\exp\left(\frac{h(T) - x}{h(T)}\right)\frac{1}{h(T)}. \end{aligned}$$

$h(T), g(T)$: O'Neill

Aspects of insect lifecycles

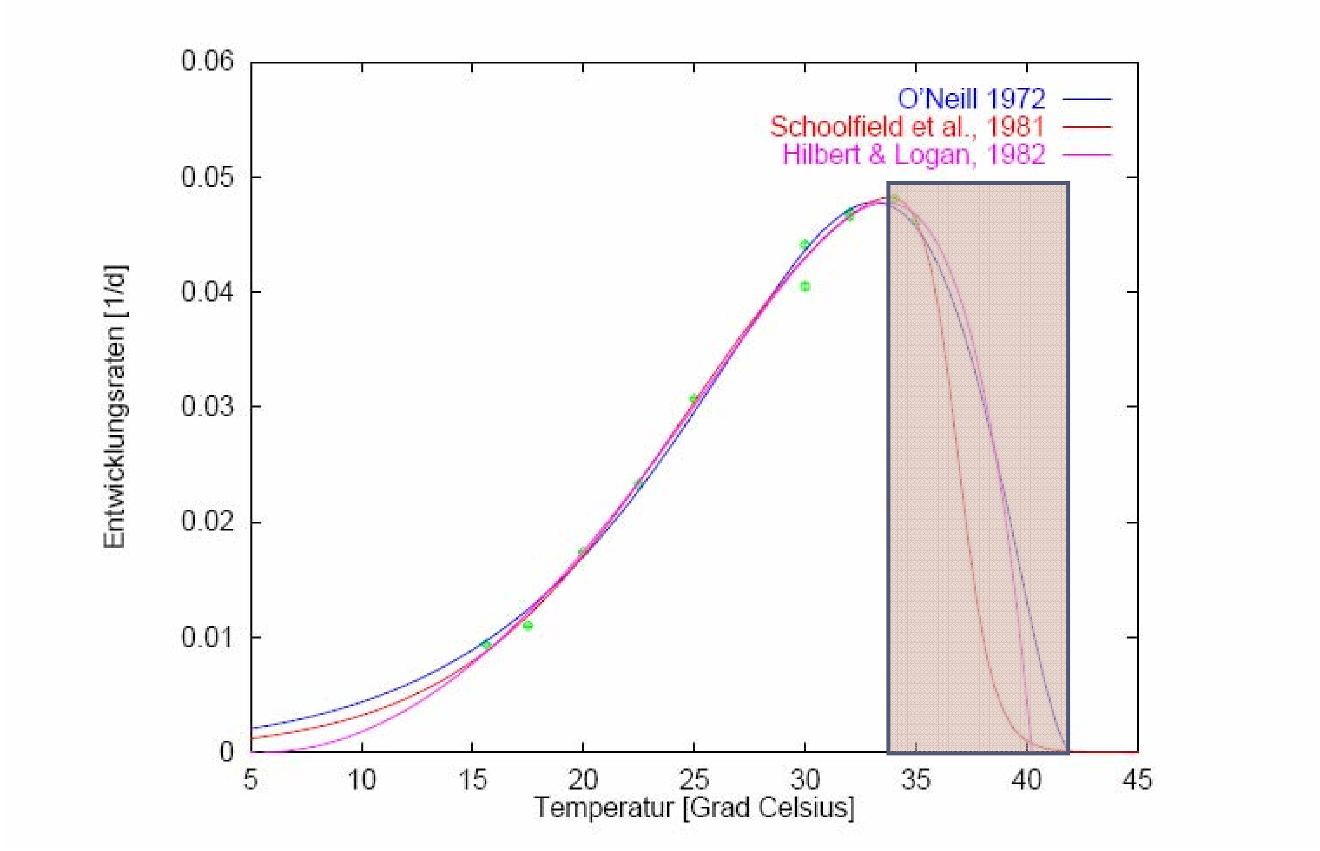
Fecundity



Rhopalosiphum padi

Conclusion

Insect population dynamics and global warming



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Further reading

- HAL CASWELL. Matrix Population Models.
  Sinauer 2001
  ISBN 0-87893-096-5
- THOMAS SELHORST. Modelling, Simulation and optimal Control of insect populations in agro-ecosystems.
  DHS 2000.
  ISBN 3-8267-1184-X