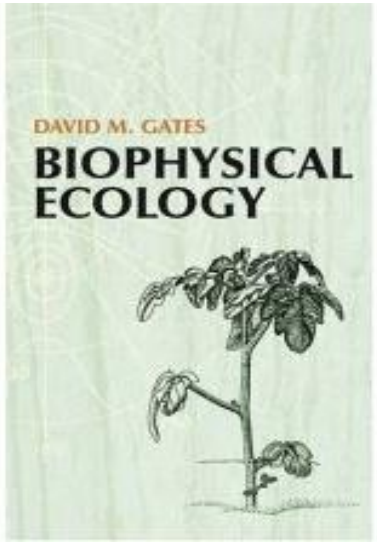
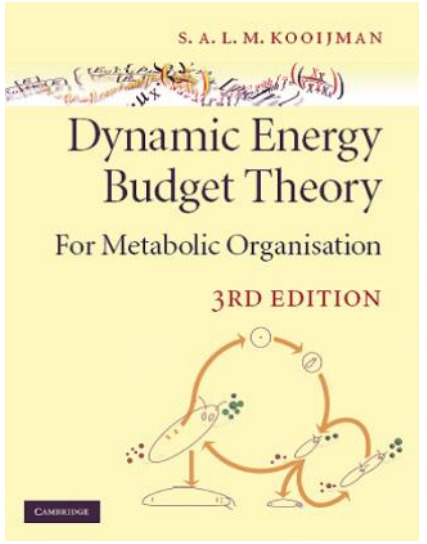


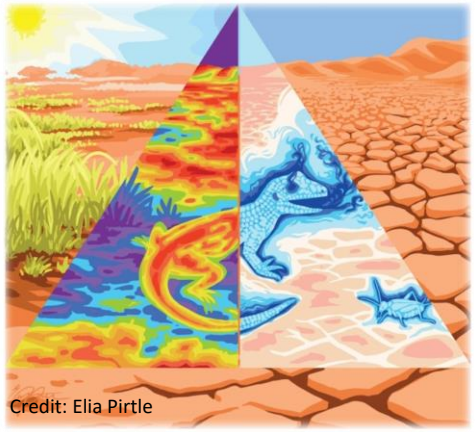


Using DEB to model environmental limits

Michael Kearney

School of BioSciences

THE UNIVERSITY OF MELBOURNE


Credit: Elia Pirtle

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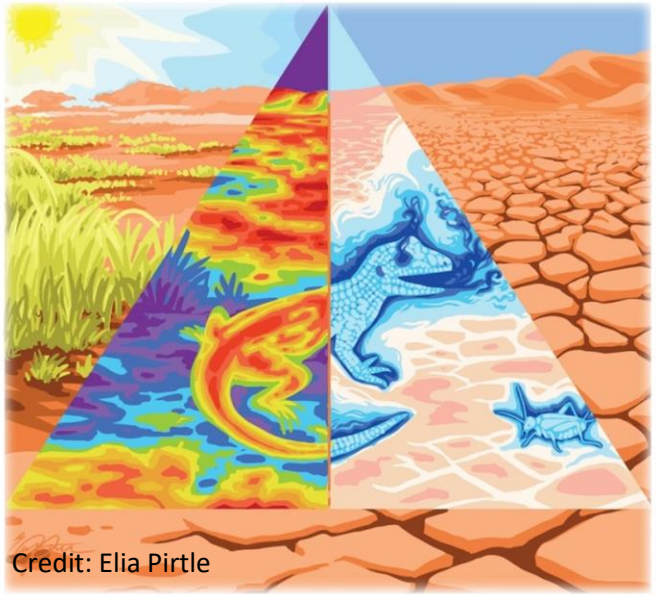
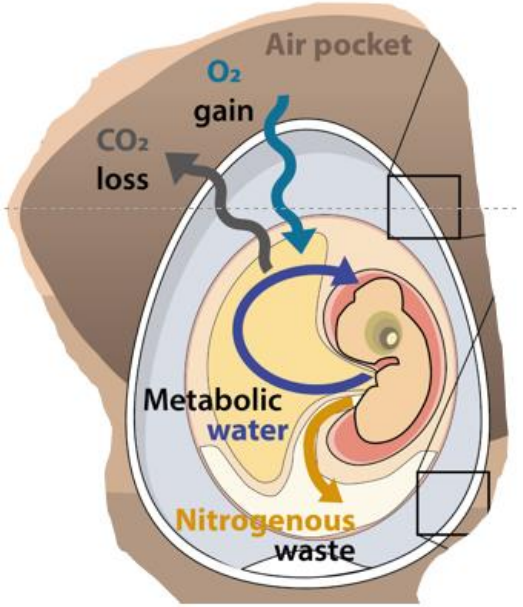
Topics

- egg water exchange
- thermal vs hydric limits in two widespread lizards
- lifecycle constraints on a butterfly


Credit: Elia Pirtle

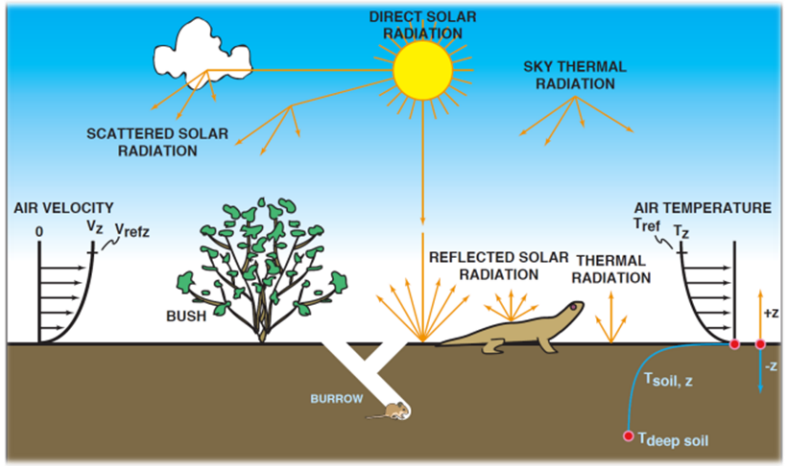


NicheMapR Ectotherm Model

ECOGRAPHY

Software note

NicheMapR – an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models



Michael R. Kearney and Warren P. Porter

M. R. Kearney (https://orcid.org/0000-0002-3349-8744) ✉ (mrke@unimelb.edu.au), School of BioSciences, The Univ. of Melbourne, Parkville, VIC, Australia. – W. P. Porter, Dept of Zoology, The Univ. of Wisconsin, Madison, WI, USA.

Ecography
43: 85–96, 2020
doi: 10.1111/ecog.04680

Mechanistic niche models characterise the fundamental niche of an organism by determining thermodynamic constraints on its heat, water and nutritional budget, and the consequences of this for growth, development and reproduction. They can thus quantify constraints on survival, activity and, ultimately, the vital rates that deter-

Thermodynamic basis to the niche

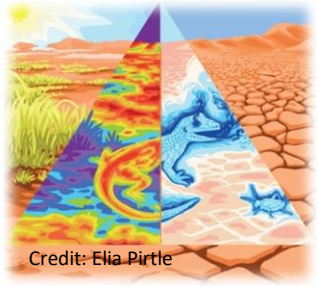
p = heat flux
J = mass flux
X = food
H = water
I = ingested
P = product (faeces)
U = urinated
G = growth
R = reproduction
S = stored
O_2 = oxygen
CO_2 = carbon dioxide
N = nitrogenous waste
MET = 'metabolism'
EVAP = evaporation
SOLAR = solar radiation
IR = infrared radiation
CONV = convection
COND = conduction

$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{J, p\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P}$$

$$= p_{IR,out} + J_{CO2,MET} + J_{N,MET} + p_{CONV} + J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \{J, p\}_{EVAP} + p_{COND}$$

heat

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$



Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

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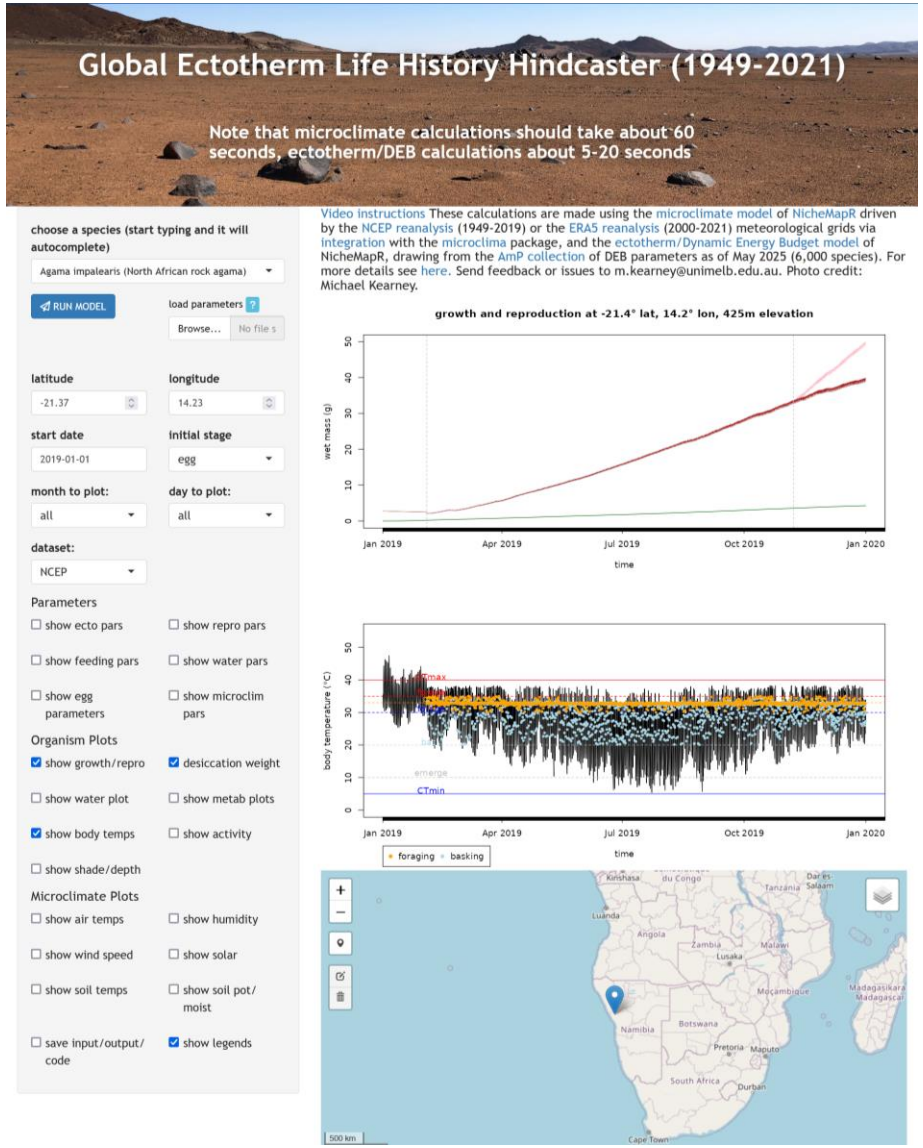

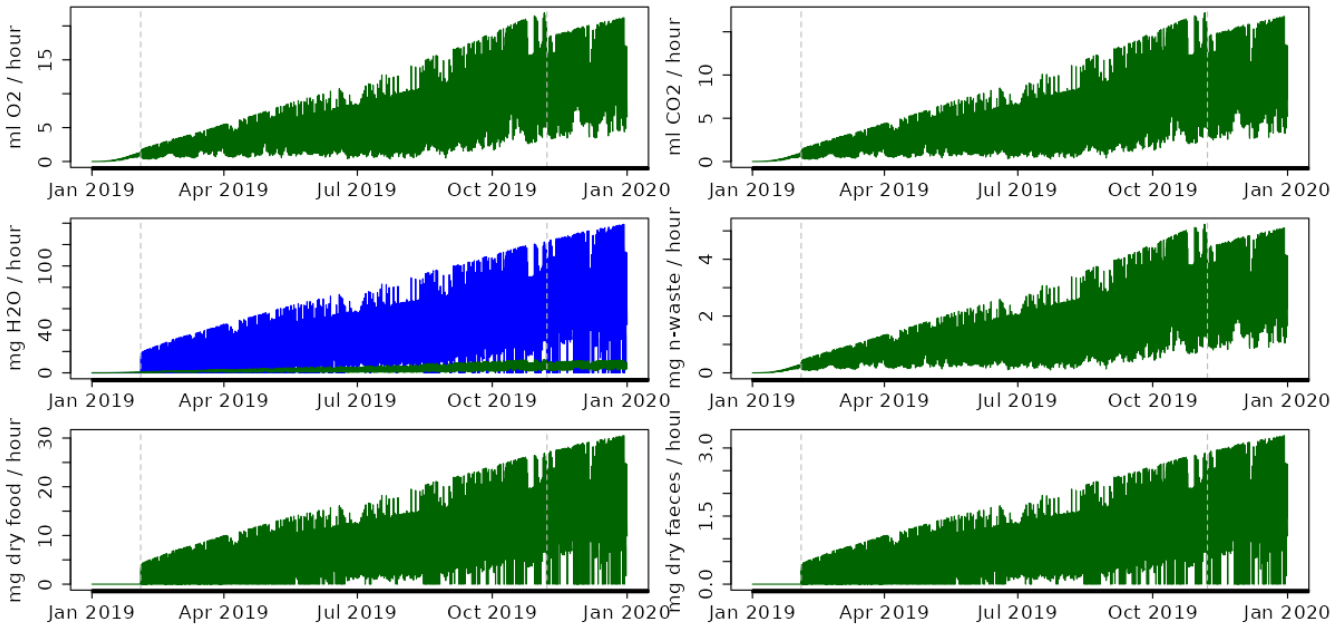

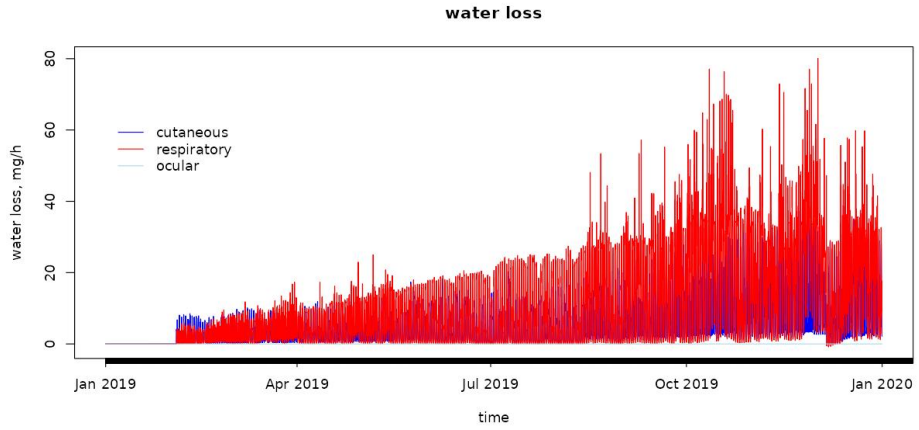

http://bioforecasts.science.unimelb.edu.au/app_direct/ecto_deb_ncep/

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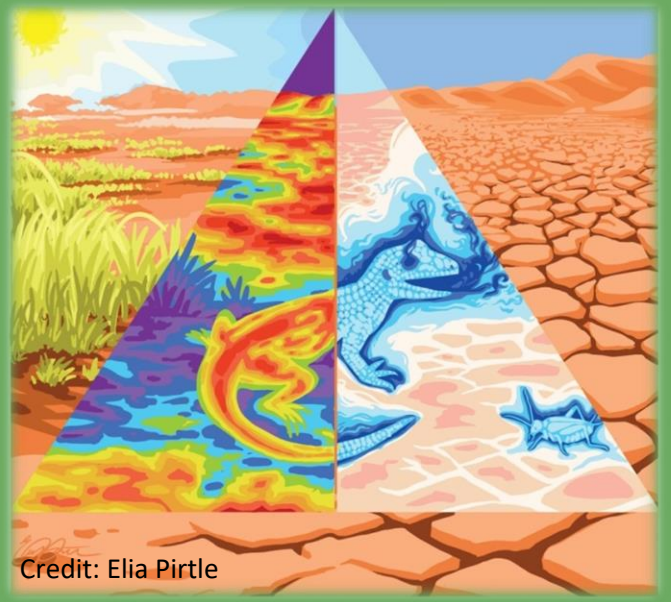

Credit: Elia Pirtle

1.

Egg water exchange

Power of combining heat, water and energy budgets

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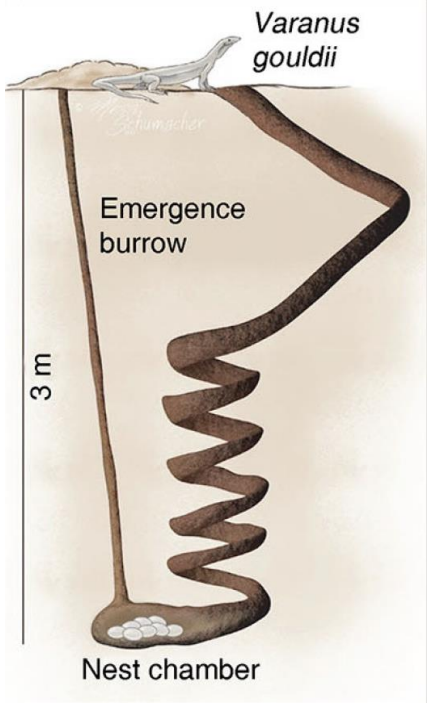
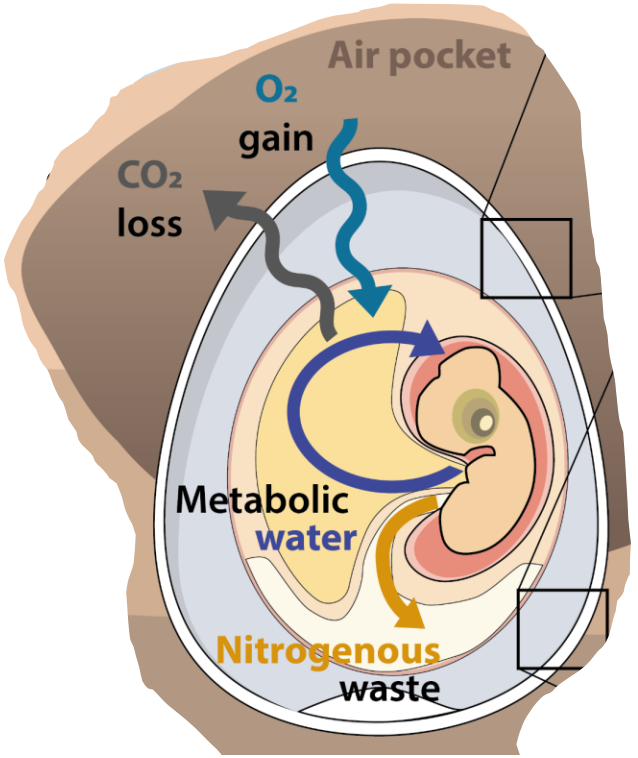
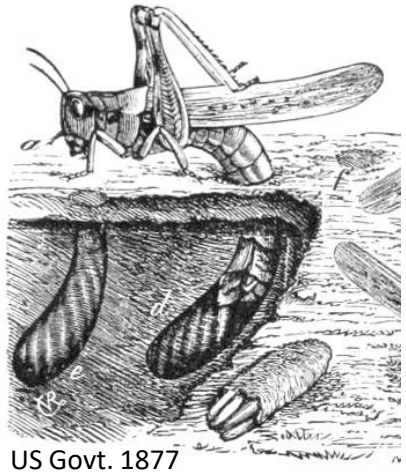
A general framework for jointly modelling thermal and hydric constraints on developing eggs



Doody et al. 2021


Photo: Tim Pascoe




US Govt. 1877

Michael R. Kearney[1] and Urtzi Enriquez-Urzelai[2]

[1]School of BioSciences, The University of Melbourne, Victoria 3010, Australia;

[2]Czech Academy of Sciences, Institute of Vertebrate Biology, Květná 8, 60365 Brno, Czech Republic

Methods in Ecology and Evolution, early view. https://doi.org/10.1111/2041-210X.14018

@ecophys

Water exchange theory

egg water balance with environment

$$\dot{m}_{st} = \dot{m}_s - \dot{m}_a$$

Fick's law

$$\dot{m}_a = \frac{\rho_e - \rho_a}{1/(A_e h_d) + 1/(A_e K_v)}$$

water vapour density gradient

boundary layer resistance

eggshell resistance

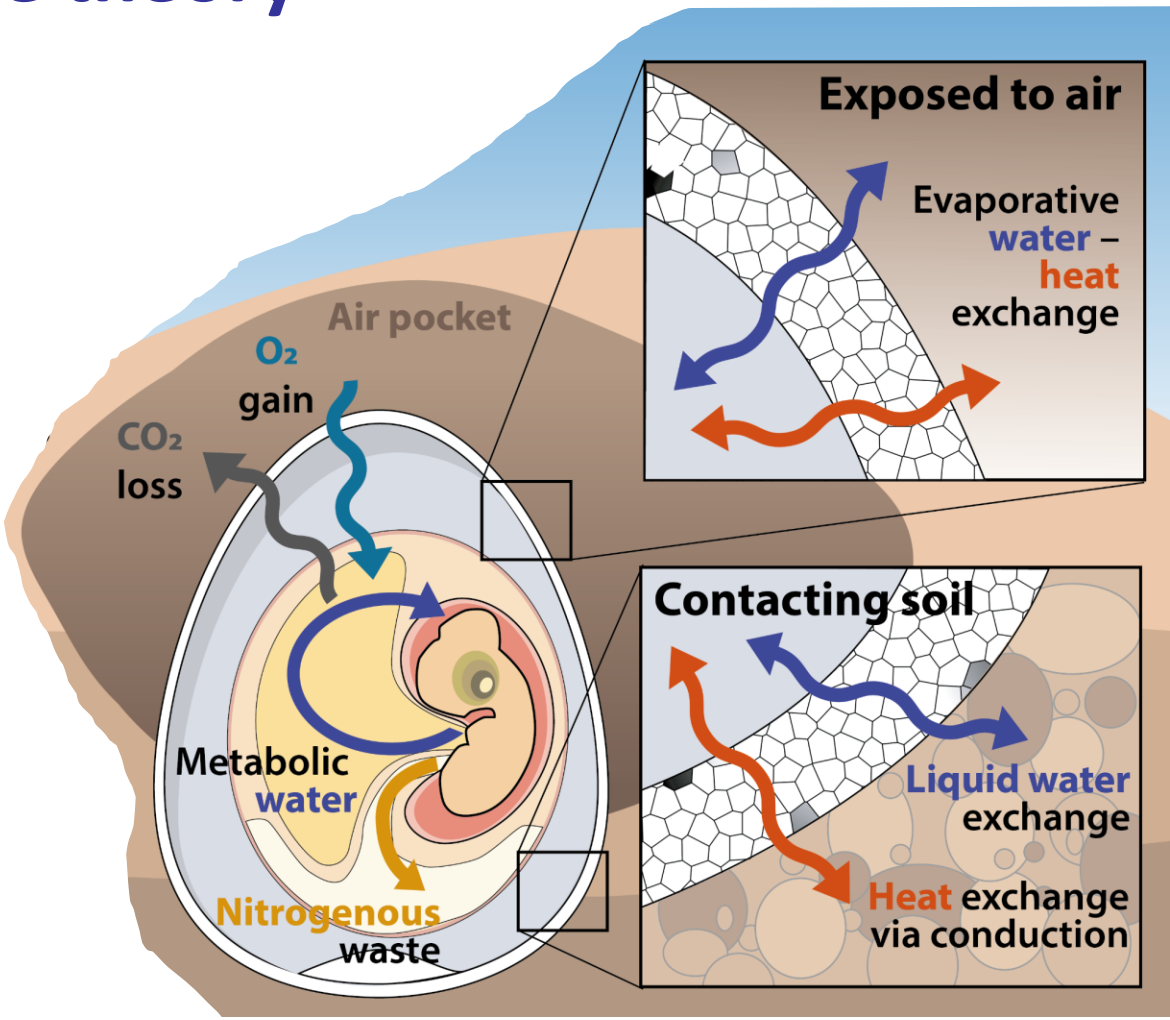
Darcy's law

$$\dot{m}_s = \frac{\psi_s - \psi_e}{1/(A_s K_e) + 1/[(2\pi A_s)^{1/2} k_s]}$$

water potential gradient

egg hydraulic resistance

soil hydraulic resistance



Water exchange theory

WATER RELATIONS OF CHELONIAN EGGS[1]

C. RICHARD TRACY, GARY C. PACKARD, AND MARY J. PACKARD

1978, Physiological Zoology, *51*(4), 378–387.

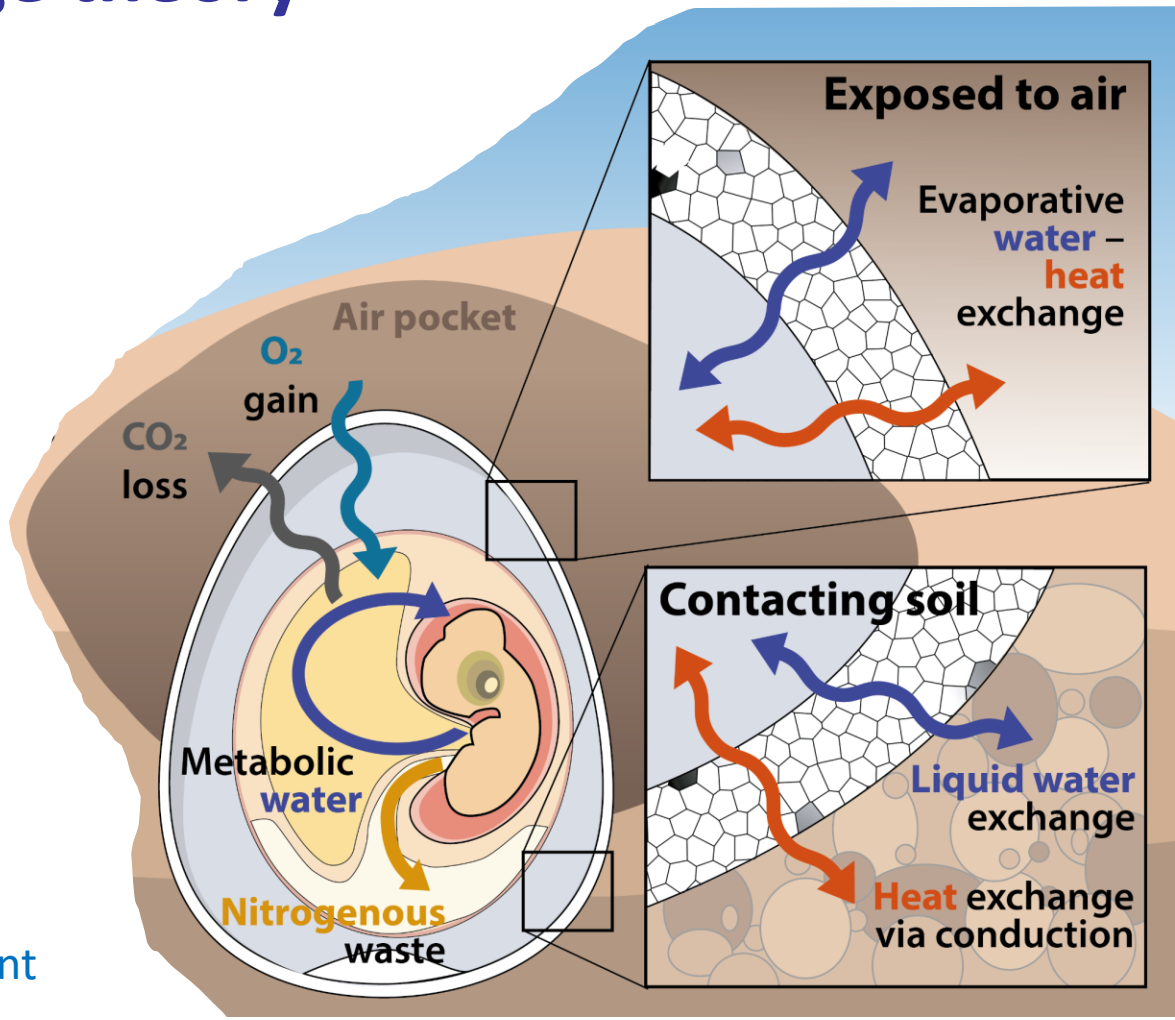
"Water exchanges are especially sensitive to such factors as substrate water potential … hydraulic conductance of the egg shell"

Copeia, 1985(3), pp. 703–711

Water and Heat Exchange between Parchment-shelled Reptile Eggs and Their Surroundings

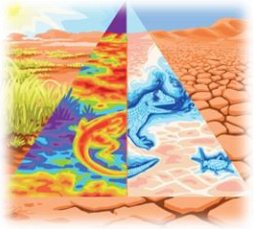
RALPH A. ACKERMAN, RICHARD C. SEAGRAVE, RAZI DMI'EL AND AMOS AR

"Exchange of water vapor rather than liquid water appears to account for the observed changes in egg mass. The thermal conductivity of the substrate can be shown to have an important effect on the exchange of heat and water by the eggs"



NicheMapR implementation

Credit: Elia Pirtle



Software note

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Ecography
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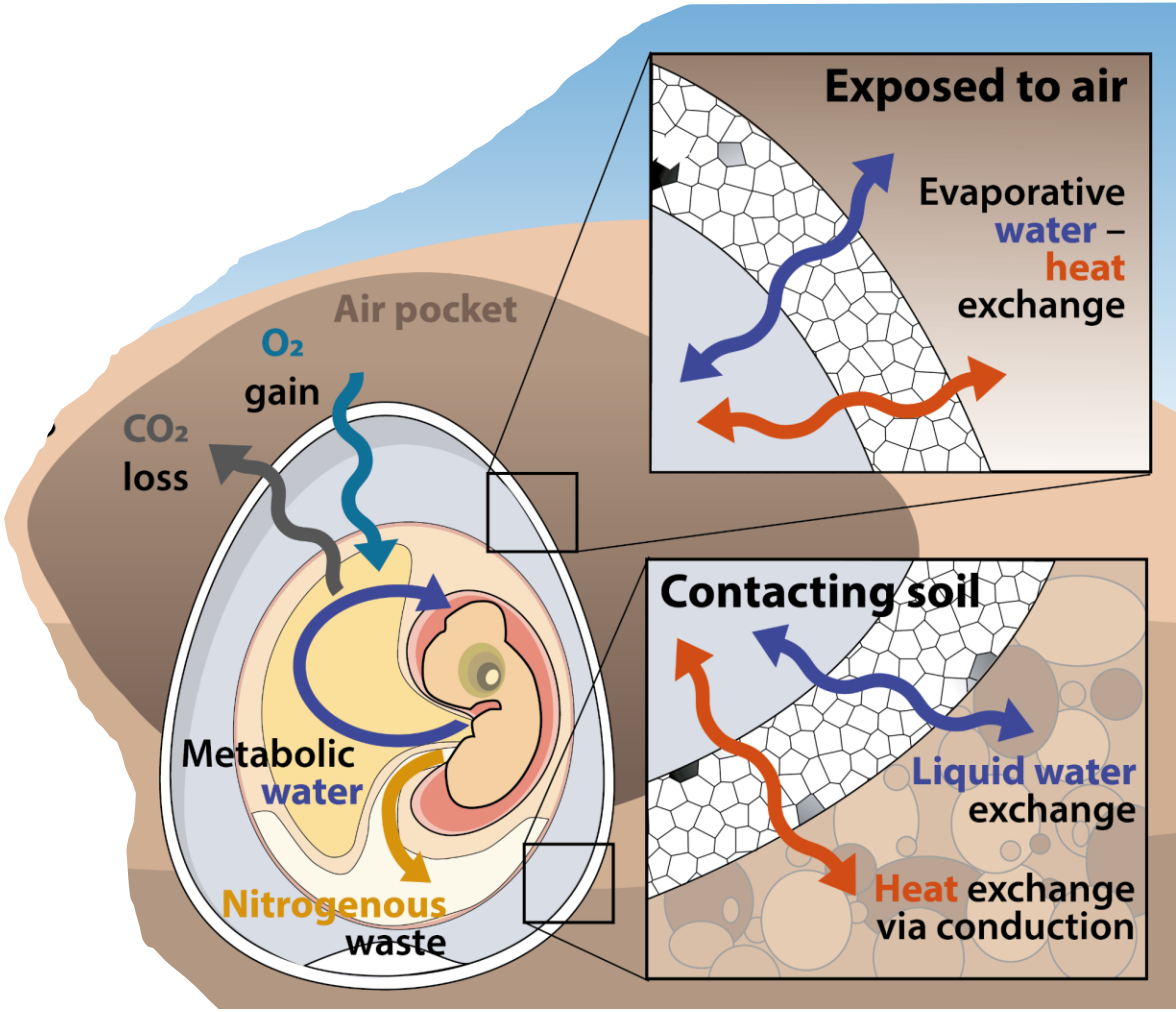
$$Q_{SOLAR} + Q_{IR,in} + J_{O2,MET} + \left(\frac{Q}{J}\right)_{MET} + J_{X,I} = J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P} = Q_{IR,out} + J_{CO2,MET} + Q_{CONV} + J_{N,MET} + J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \left(\frac{Q}{J}\right)_{EVAP} + Q_{COND} + Q_S$$

heat

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$



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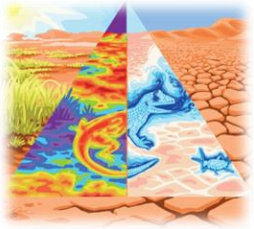

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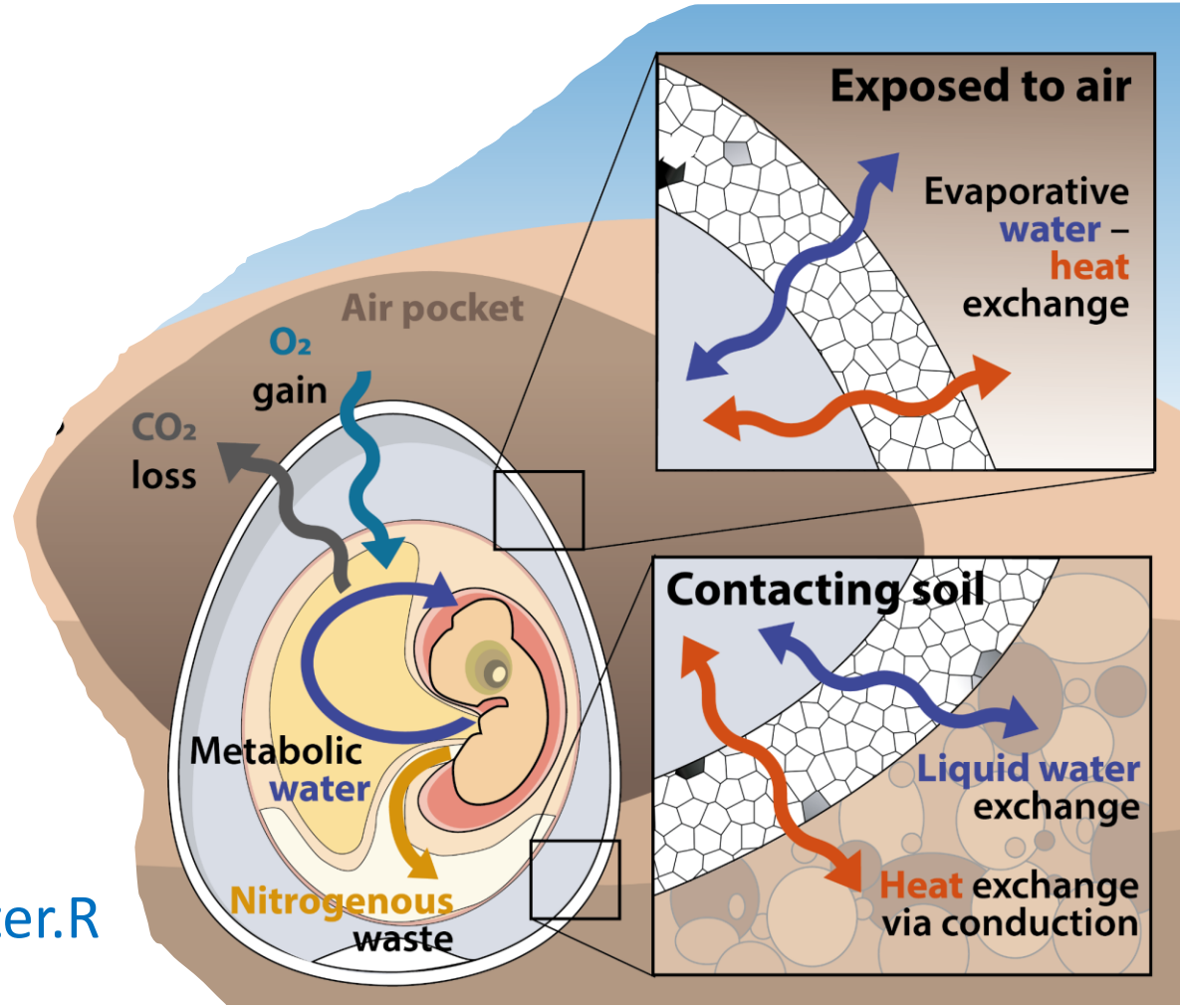
Fick's law

$$\dot{m}_a = \frac{\rho_e - \rho_a}{1/(A_e h_d) + 1/(A_e K_v)}$$

Darcy's law

$$\dot{m}_s = \frac{\psi_s - \psi_e}{1/(A_s K_e) + 1/[(2\pi A_s)^{1/2} k_s]}$$

egg_water.R



Tracy et al. 1978 egg water budget model (requires the deSolve package)

Description

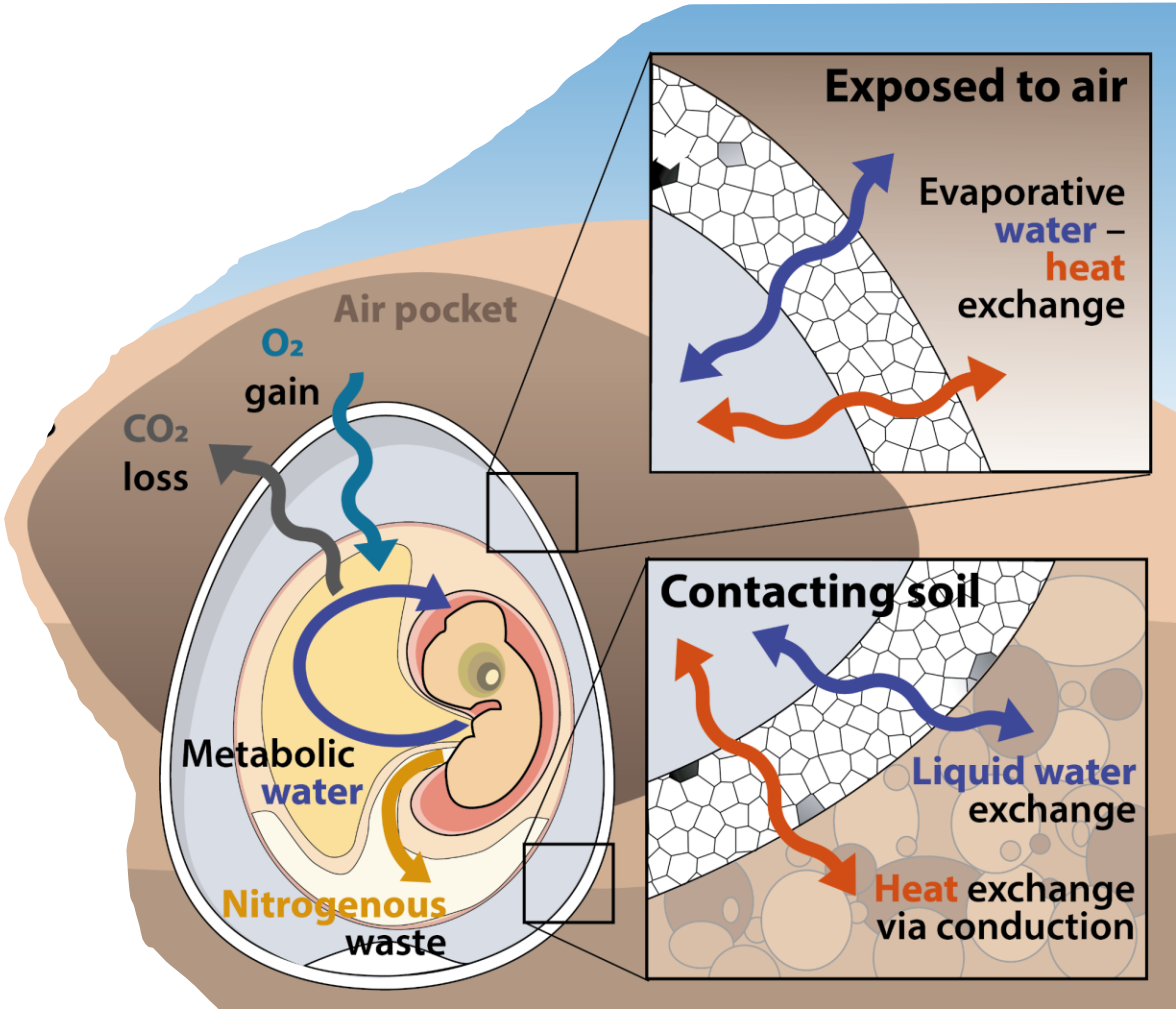
Function for computing the exchange of gaseous and liquid water between an egg and soil under environmental conditions that vary with time, using interpolation functions to estimate environmental conditions at particular time intervals. Michael Kearney developed this R function based on Tracy, C. R., Packard, G. C., and Packard, M. J. (1978). Water relations of chelonian eggs. Physiological Zoology 51, 378–387. Parameter examples come from this paper.

Usage

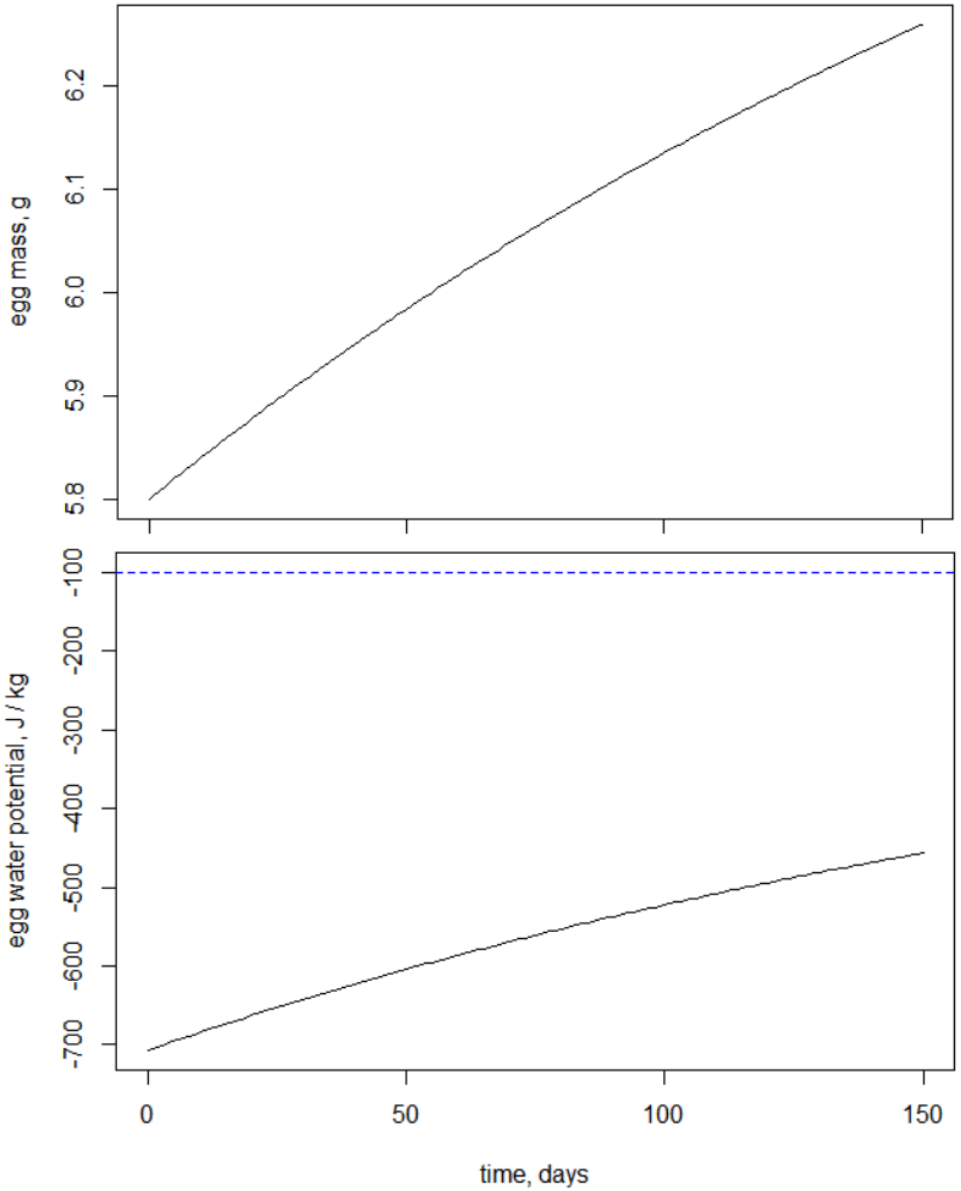
```
ode(y = c(m_init, psi_e_init), times = t, func = egg_water, parms = indata)
```

Arguments

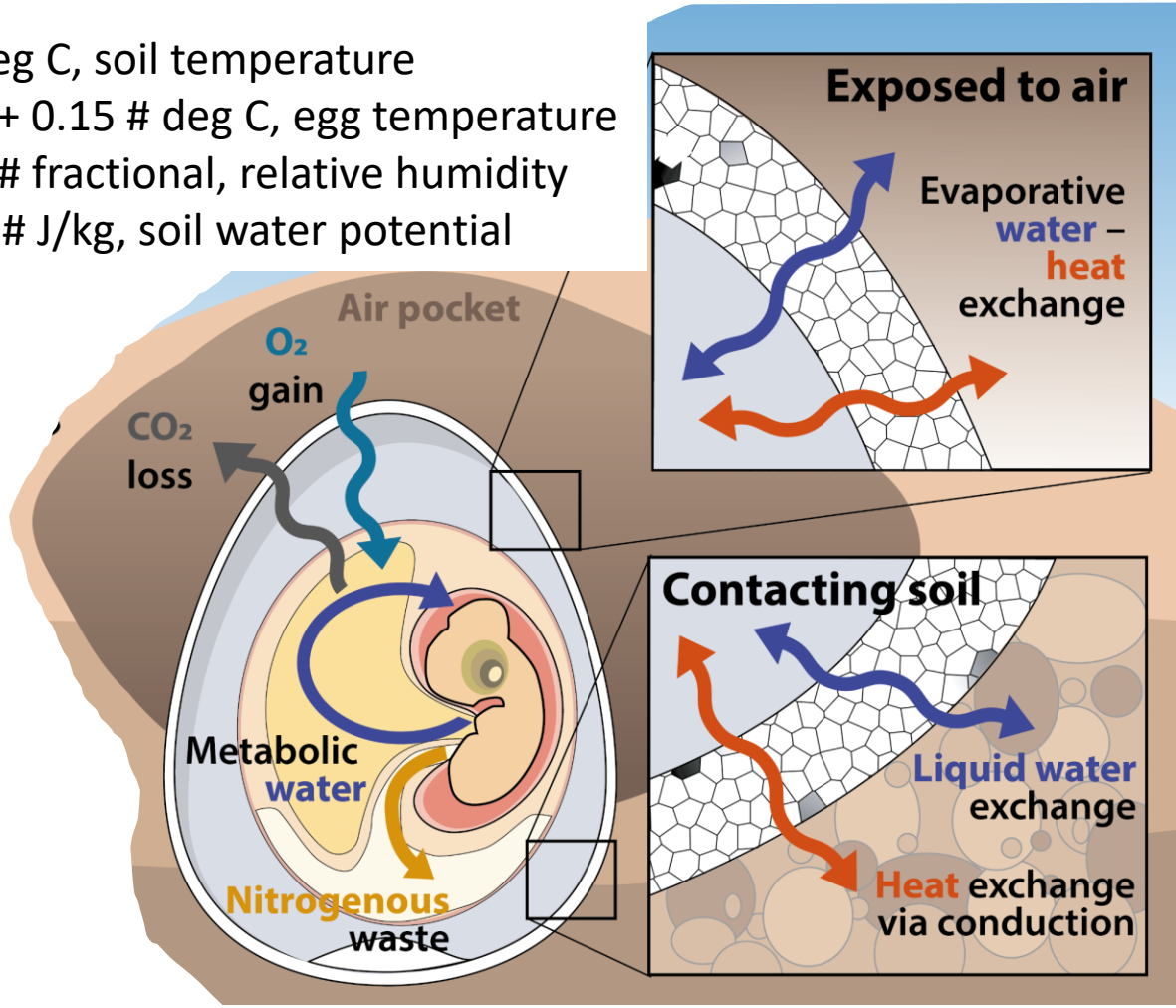
t	time intervals (s) at which output is required
m_init	= 5.8 / 1000, mass of freshly laid egg (kg)
psi_e_init	= -707, water potential of freshly laid egg (J/kg)
shape	= 0.6, ratio of minor axes major axis of ellipsoid (-)
f_air	= 0.5, fraction of egg surface exposed to air
K_e	= 1.12 * 60 * 24 / 1e6 / (3600 * 24 * 10), hydraulic conductance of egg (kg m-2 s-1 (J/kg)-1), converted from original µg cm-2 min-1 bar-1
spec_hyd	= 0.5, water potential-specific hydration (m3 m-3 (J/kg)-1)
pct_wet	= 0.24, percent of surface area acting as a free-water surface for evaporation (%)
P_e	= -0.5052209, soil air entry potential (J/kg), derived from soil texture data via the function 'pedotransfer' and used to get soil hydraulic conductivity
b	= 1.41005, Campbell's b parameter (-), derived from soil texture data via the function 'pedotransfer' and used to get soil hydraulic conductivity
K_sat	= 0.003733307, soil saturated hydraulic conductivity (kg m-1 s-1 (J/kg)-1) derived from soil texture data via the function 'pedotransfer' and used to get soil hydraulic conductivity
elev	= 0, elevation (m), needed for properties of air
vel	= 0.001, wind speed (m/s)
Tsoilf	soil temperature function with time, generated by 'approxfun' (°C)
Tbf	body temperature function with time, generated by 'approxfun'(°C)
RHsoilf	relative humidity function with time, generated by 'approxfun' (fractional)
PSIsoilf	soil water potential with time, generated by 'approxfun' (J/kg)

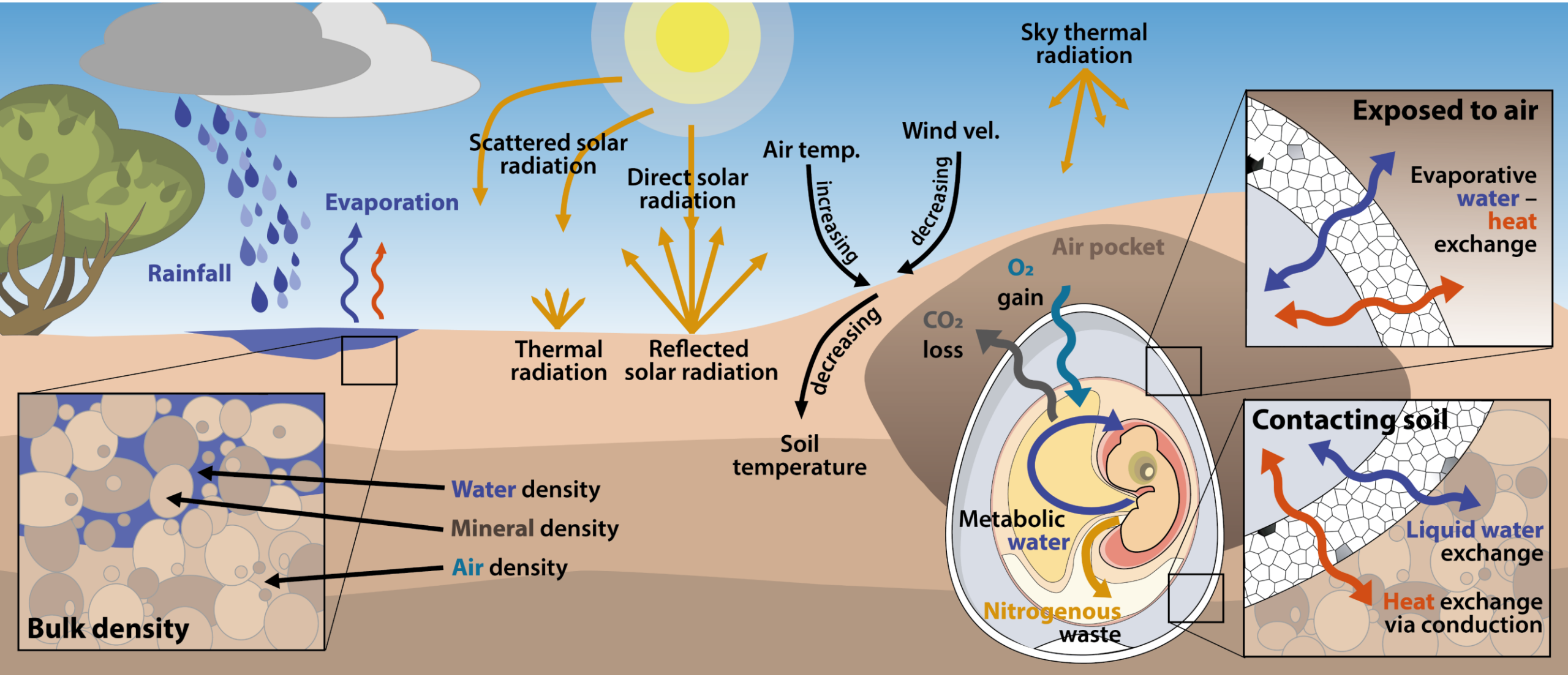


NicheMapR implementation




```
T_soil <- 29 # deg C, soil temperature
T_egg <- T_soil + 0.15 # deg C, egg temperature
RH_soil <- 0.99 # fractional, relative humidity
PSI_soil <- -100 # J/kg, soil water potential
```




Sky thermal radiation
Scattered solar radiation
Direct solar radiation
Air temp.
increasing
Wind vel.
decreasing
Evaporation
Rainfall
Thermal radiation
Reflected solar radiation
decreasing
Soil temperature
Air pocket
O2 gain
CO2 loss
Metabolic water
Nitrogenous waste
Exposed to air
Evaporative water – heat exchange
Contacting soil
Liquid water exchange
Heat exchange via conduction
Water density
Mineral density
Air density
Bulk density

NicheMapR implementation

Copeia, 1985(3), pp. 703–711

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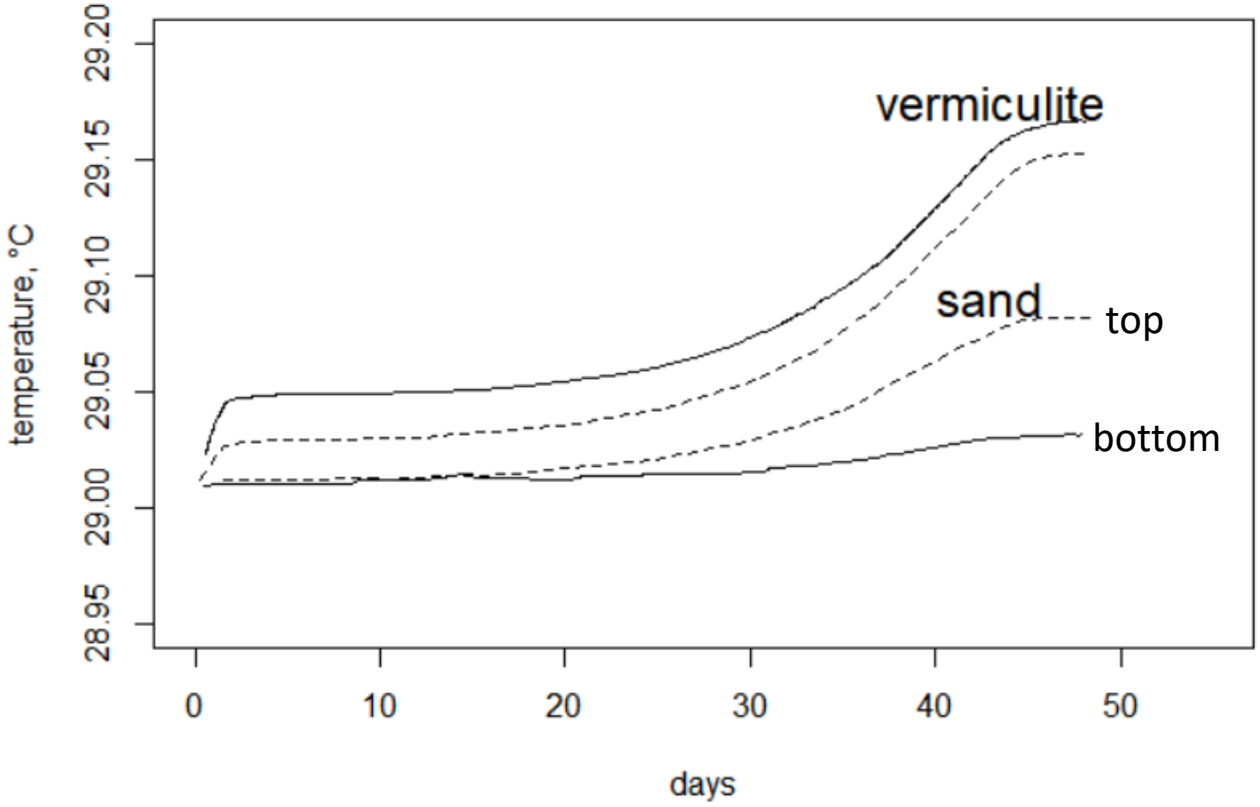
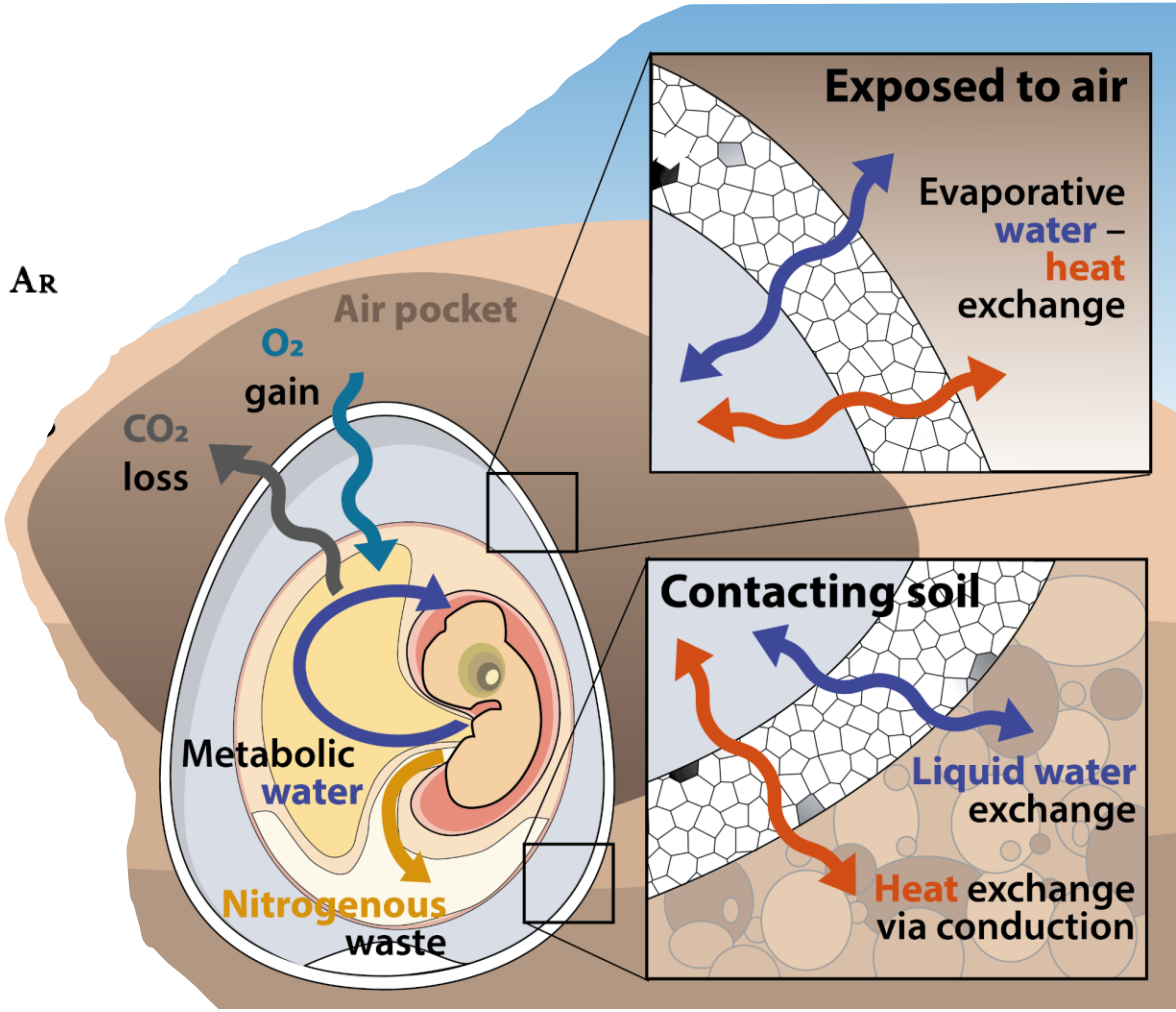
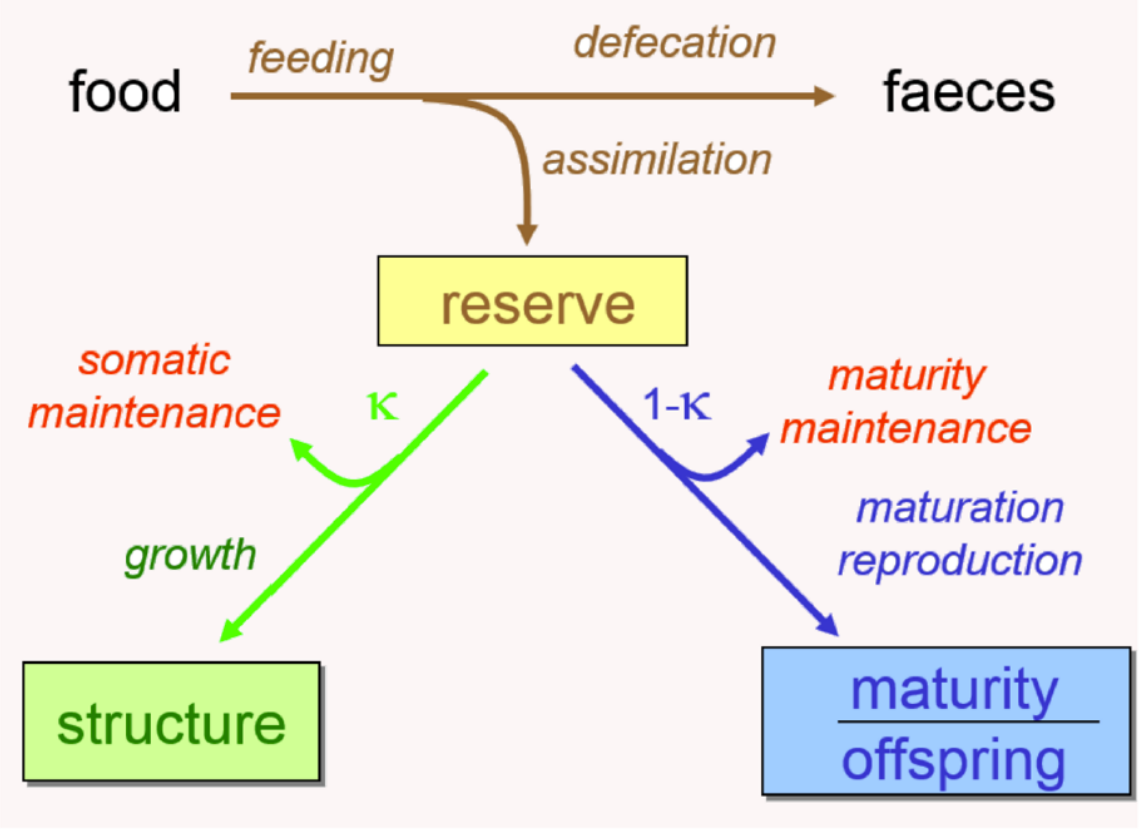




Integrating metabolic theory



Dynamic Energy Budget theory

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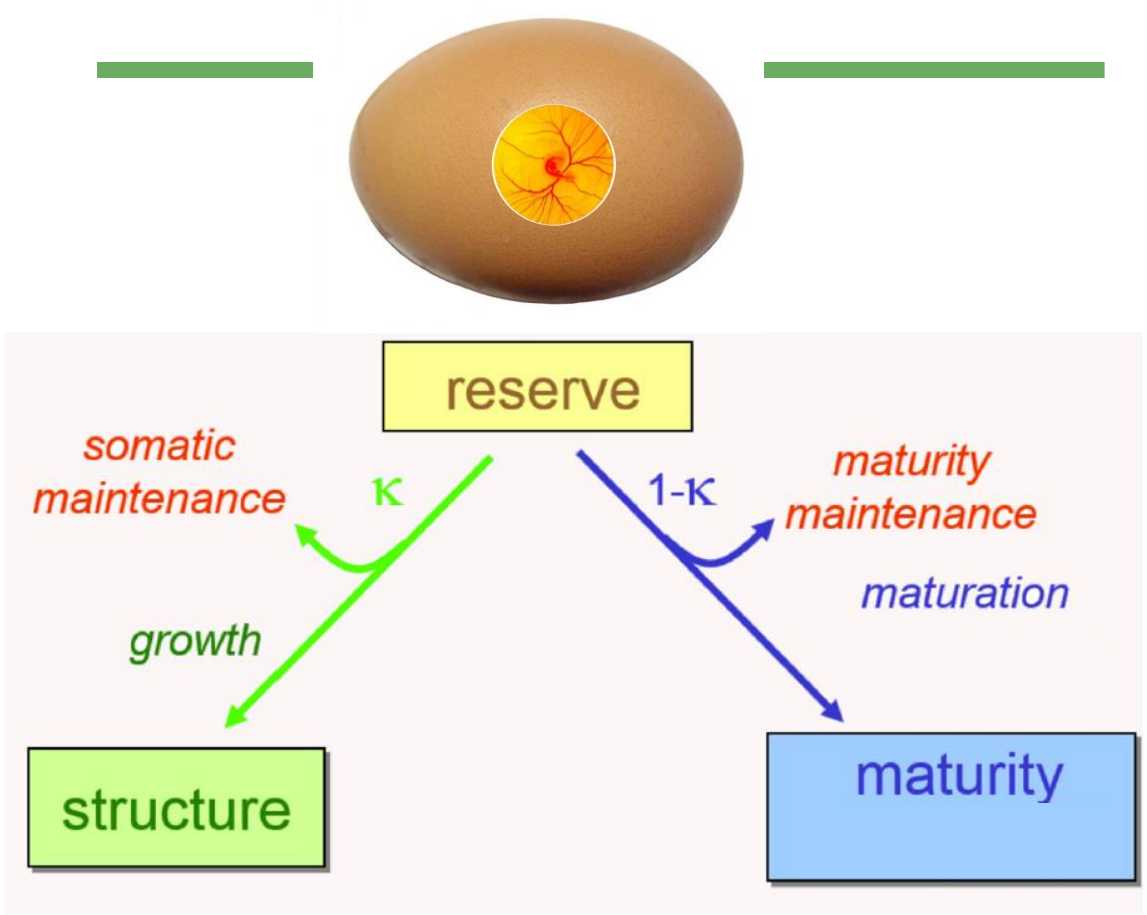
Integrating metabolic theory



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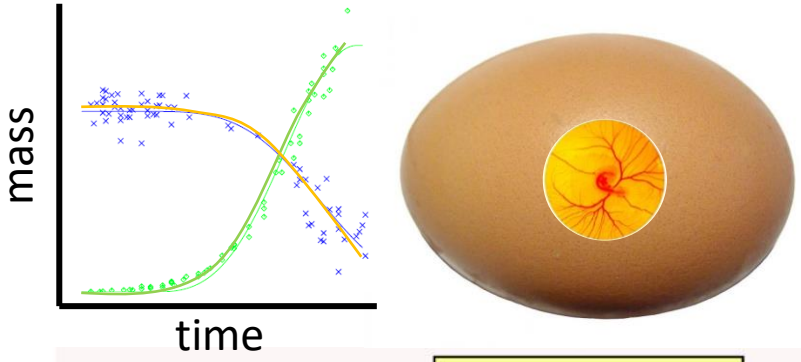

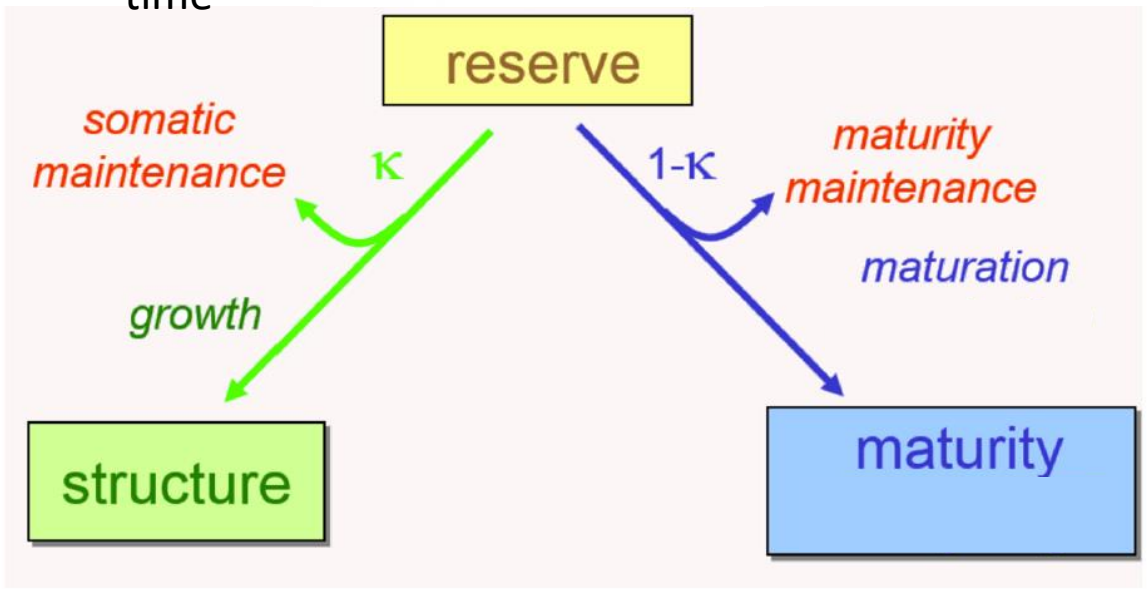

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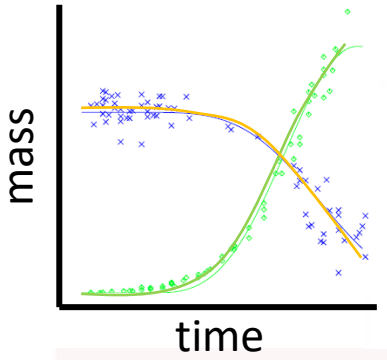

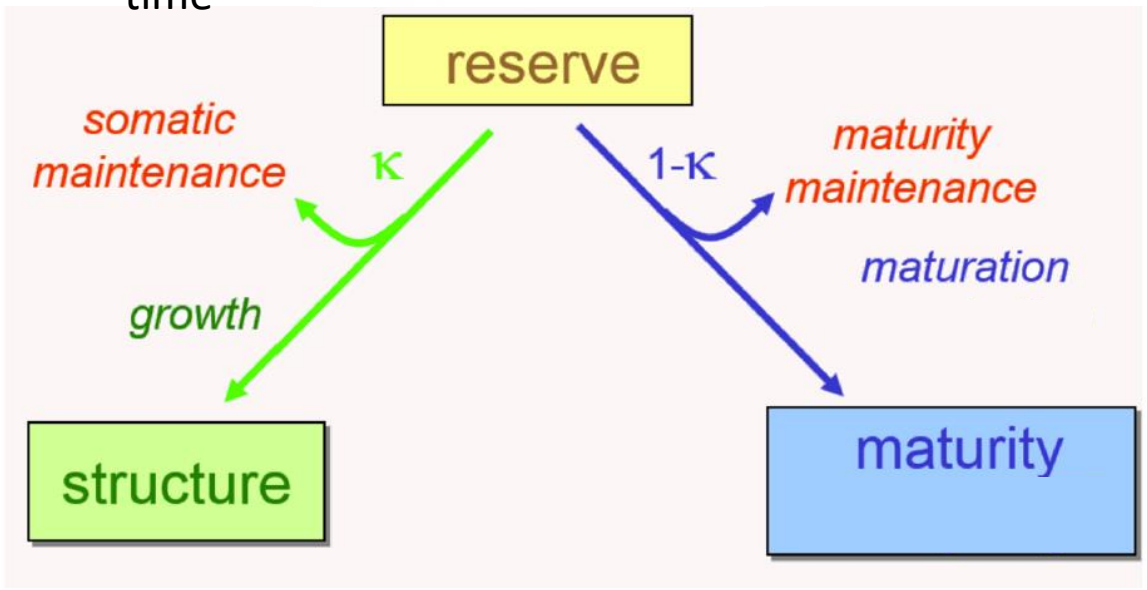

Stoichiometry

$$\mathbf{N}_{org} = \begin{array}{c|cccc} & X & E & V & P \\ \hline & 1 & 1 & 1 & 1 \\ & n_{HX} & n_{HE} & n_{HV} & n_{HP} \\ & n_{OX} & n_{OE} & n_{OV} & n_{OP} \\ & n_{NX} & n_{NE} & n_{NV} & n_{NP} \end{array} \begin{array}{l} C \\ H \\ O \\ N \end{array} \quad \mathbf{N}_{met} = \begin{array}{c|cccc} & CO_2 & H_2O & O_2 & NH_3 \\ \hline & 1 & 0 & 0 & 0 \\ & 0 & 2 & 0 & 3 \\ & 2 & 1 & 2 & 0 \\ & 0 & 0 & 0 & 1 \end{array} \begin{array}{l} C \\ H \\ O \\ N \end{array}$$

Growth

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OG}O_2 \xrightarrow{j_{EG}} y_{VE}CH_{nHV}O_{nOV}N_{nNV} + c_{CG}CO_2 + c_{HG}H_2O + c_{NG}NH_3$$

Reserve (E) → Structure (V)

Dissipation

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OD}O_2 \xrightarrow{j_{ED}} c_{CD}CO_2 + c_{HD}H_2O + c_{ND}NH_3$$

Reserve (E)

Dynamic Energy Budget theory

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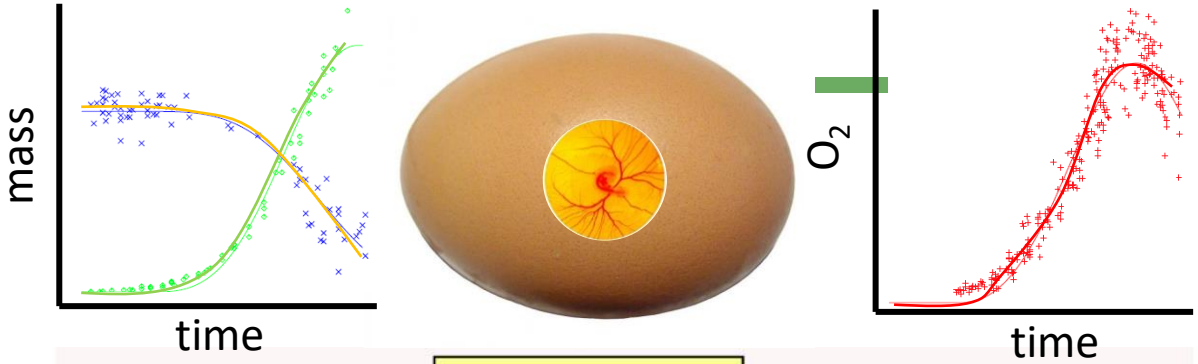

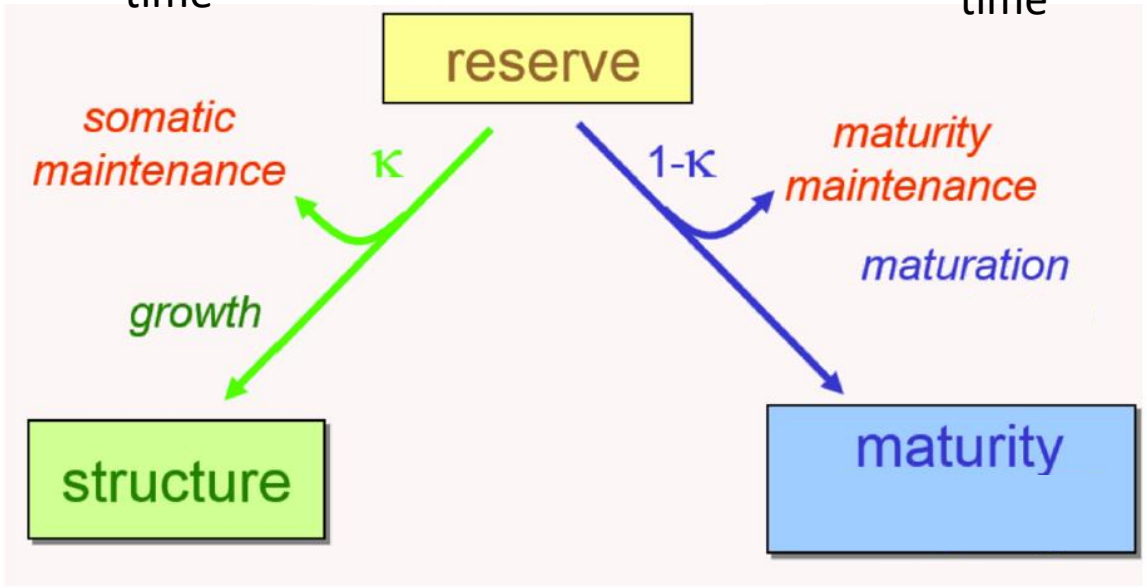

Stoichiometry

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Reserve (E) → Structure (V)

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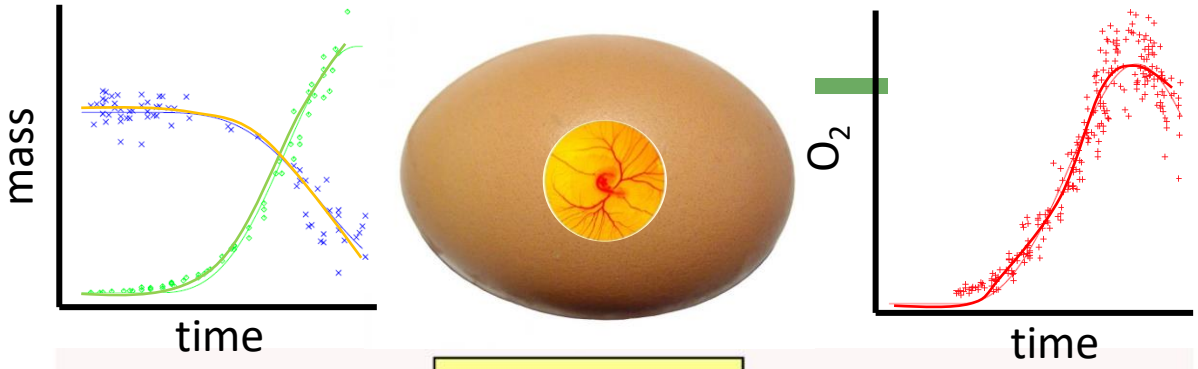
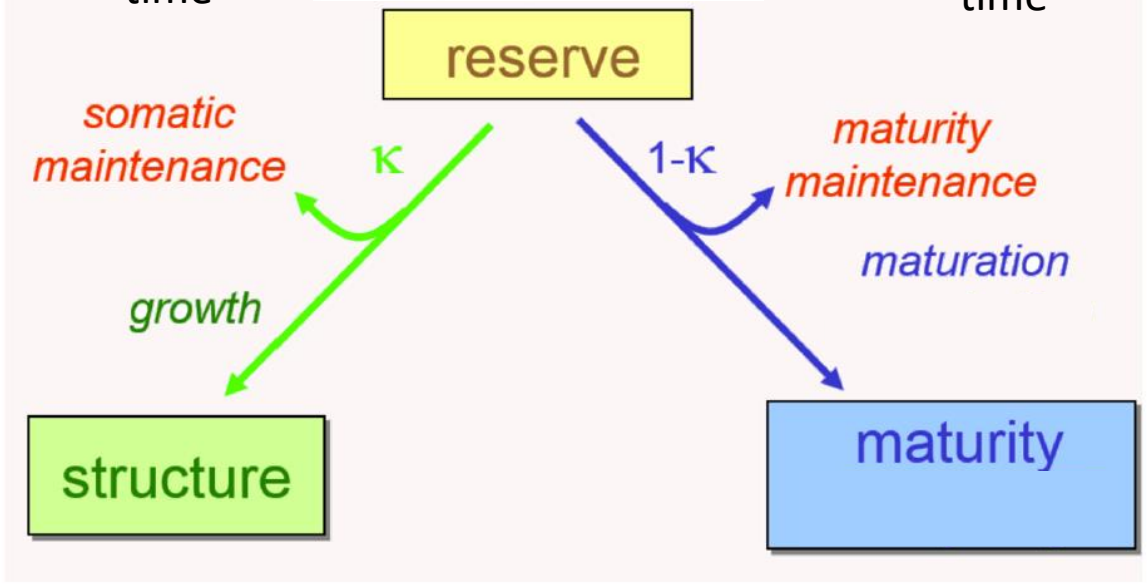
Integrating metabolic theory





Stoichiometry

$$\mathbf{N}_{org} = \begin{array}{c|cccc} & X & E & V & P \\ \hline & 1 & 1 & 1 & 1 \\ C & n_{HX} & n_{HE} & n_{HV} & n_{HP} \\ H & n_{OX} & n_{OE} & n_{OV} & n_{OP} \\ O & n_{NX} & n_{NE} & n_{NV} & n_{NP} \\ N \end{array} \qquad \mathbf{N}_{met} = \begin{array}{c|cccc} & CO_2 & H_2O & O_2 & NH_3 \\ \hline C & 1 & 0 & 0 & 0 \\ H & 0 & 2 & 0 & 3 \\ O & 2 & 1 & 2 & 0 \\ N & 0 & 0 & 0 & 1 \end{array}$$

Growth

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OG}O_2 \xrightarrow{j_{EG}} y_{VE}CH_{nHV}O_{nOV}N_{nNV} + c_{CG}CO_2 + c_{HG}H_2O + c_{NG}NH_3$$

Reserve (E) → Structure (V)

Dissipation

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OD}O_2 \xrightarrow{j_{ED}} c_{CD}CO_2 + c_{HD}H_2O + c_{ND}NH_3$$

Reserve (E)

Heat

$$-\dot{Q} = \dot{W} - \bar{\mathbf{h}}_{org}^{T}\mathbf{j}_{org} - \bar{\mathbf{h}}_{met}^{T}\mathbf{j}_{met} = \dot{W} - (\bar{\mathbf{h}}_{org}^{T} - \bar{\mathbf{h}}_{met}^{T}\mathbf{N}_{met}^{-1}\mathbf{N}_{org})\mathbf{Y}\dot{J}_E$$

Dynamic Energy Budget theory

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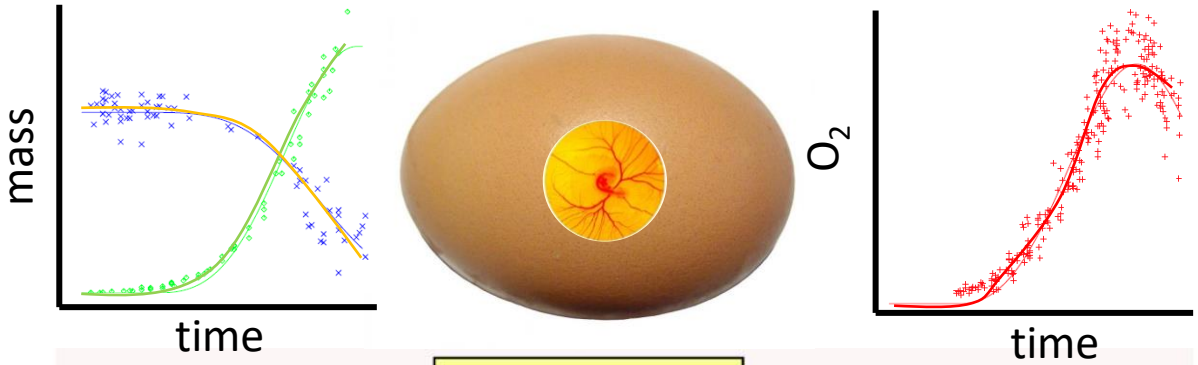
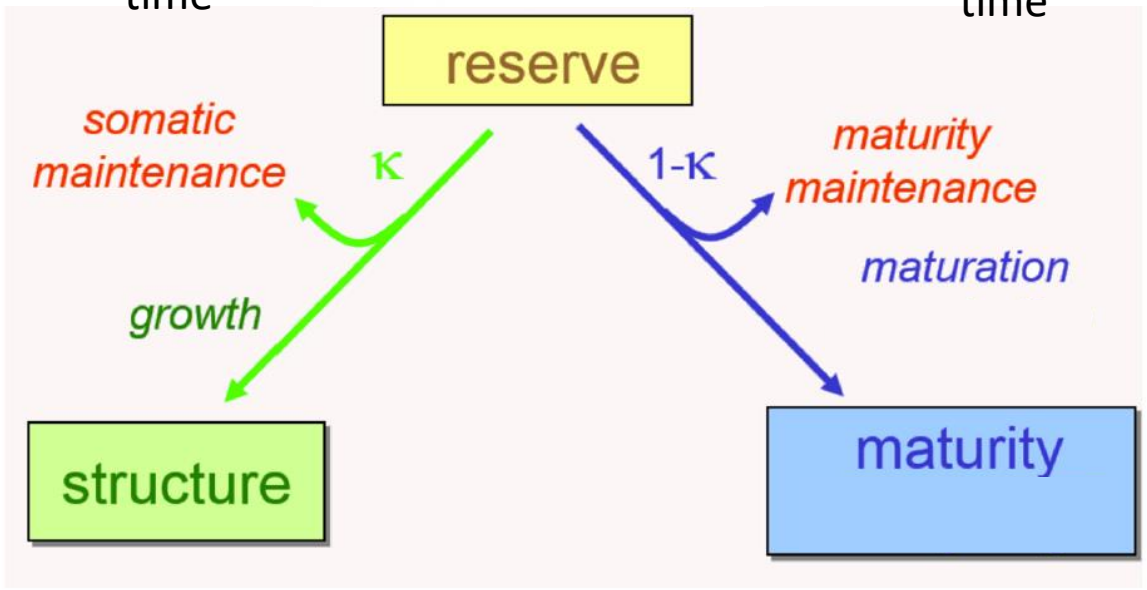
Integrating metabolic theory





Dynamic Energy Budget theory

Stoichiometry

$$\mathbf{N}_{org} = \begin{array}{c} \begin{matrix} X & E & V & P \end{matrix} \\ \begin{pmatrix} 1 & 1 & 1 & 1 \\ n_{HX} & n_{HE} & n_{HV} & n_{HP} \\ n_{OX} & n_{OE} & n_{OV} & n_{OP} \\ n_{NX} & n_{NE} & n_{NV} & n_{NP} \end{pmatrix} \end{array} \begin{matrix} C \\ H \\ O \\ N \end{matrix} \qquad \mathbf{N}_{met} = \begin{array}{c} \begin{matrix} CO_2 & H_2O & O_2 & NH_3 \end{matrix} \\ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 3 \\ 2 & 1 & 2 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array} \begin{matrix} C \\ H \\ O \\ N \end{matrix}$$

Growth

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OG}O_2 \xrightarrow{j_{EG}} y_{VE}CH_{nHV}O_{nOV}N_{nNV} + c_{CG}CO_2 + c_{HG}H_2O + c_{NG}NH_3$$

Reserve (E) → Structure (V)

Dissipation

$$CH_{nHE}O_{nOE}N_{nNE} + c_{OD}O_2 \xrightarrow{j_{ED}} c_{CD}CO_2 + c_{HD}H_2O + c_{ND}NH_3$$

Reserve (E)

Metabolic rates

$$\mathbf{j}_E = \begin{pmatrix} j_{EA} \\ j_{EG} \\ j_{ED} \end{pmatrix}$$

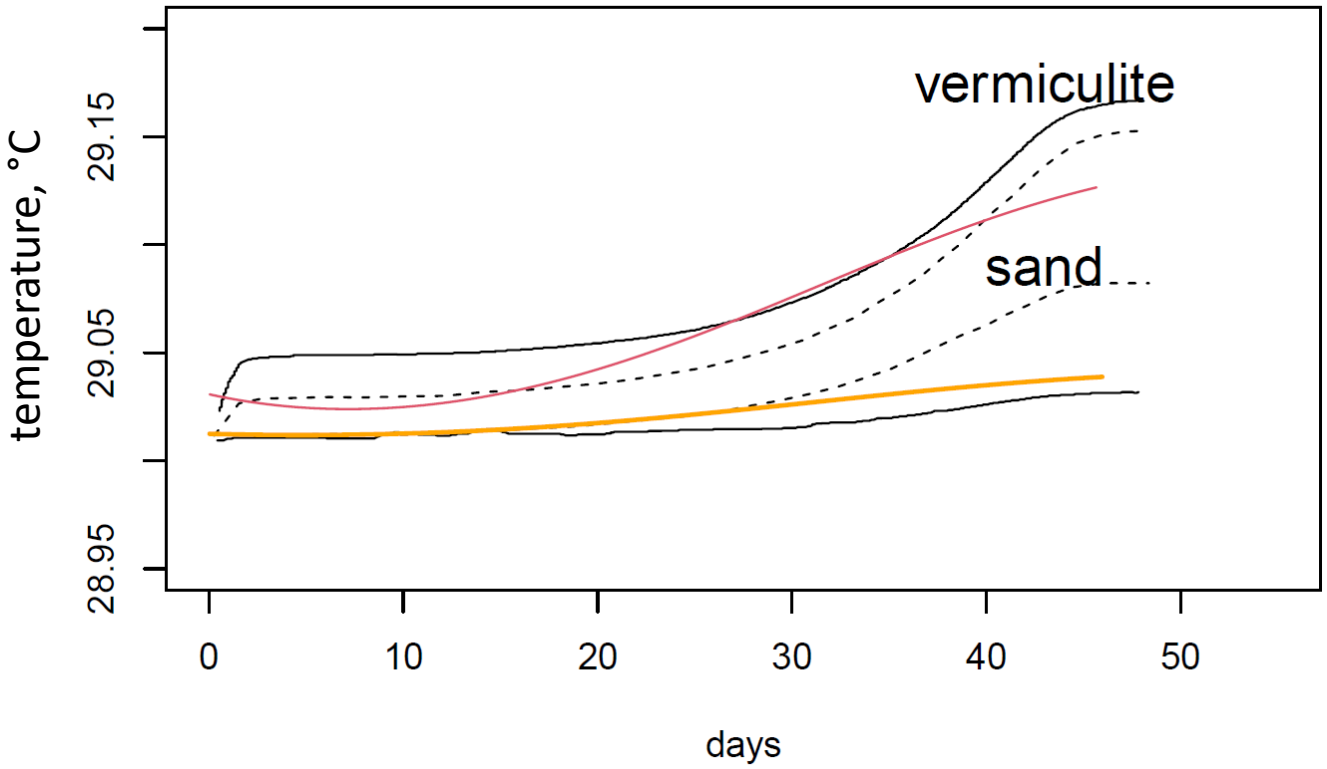
Heat

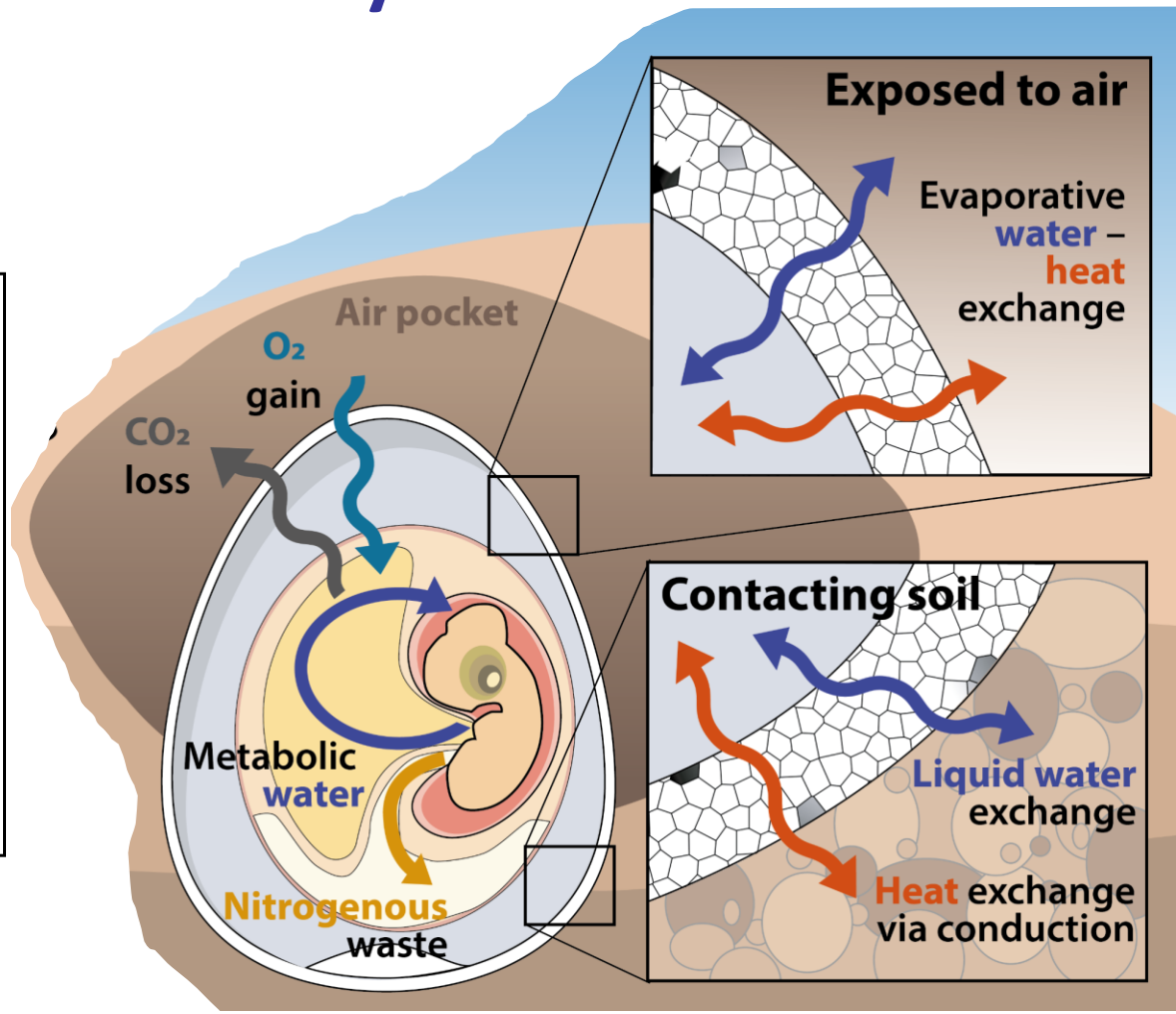
$$-\dot{Q} = \dot{W} - \bar{\mathbf{h}}_{org}^T \mathbf{j}_{org} - \bar{\mathbf{h}}_{met}^T \mathbf{j}_{met} = \dot{W} - (\bar{\mathbf{h}}_{org}^T - \bar{\mathbf{h}}_{met}^T \mathbf{N}_{met}^{-1} \mathbf{N}_{org}) \mathbf{Y} \mathbf{j}_E$$

Metabolic black box

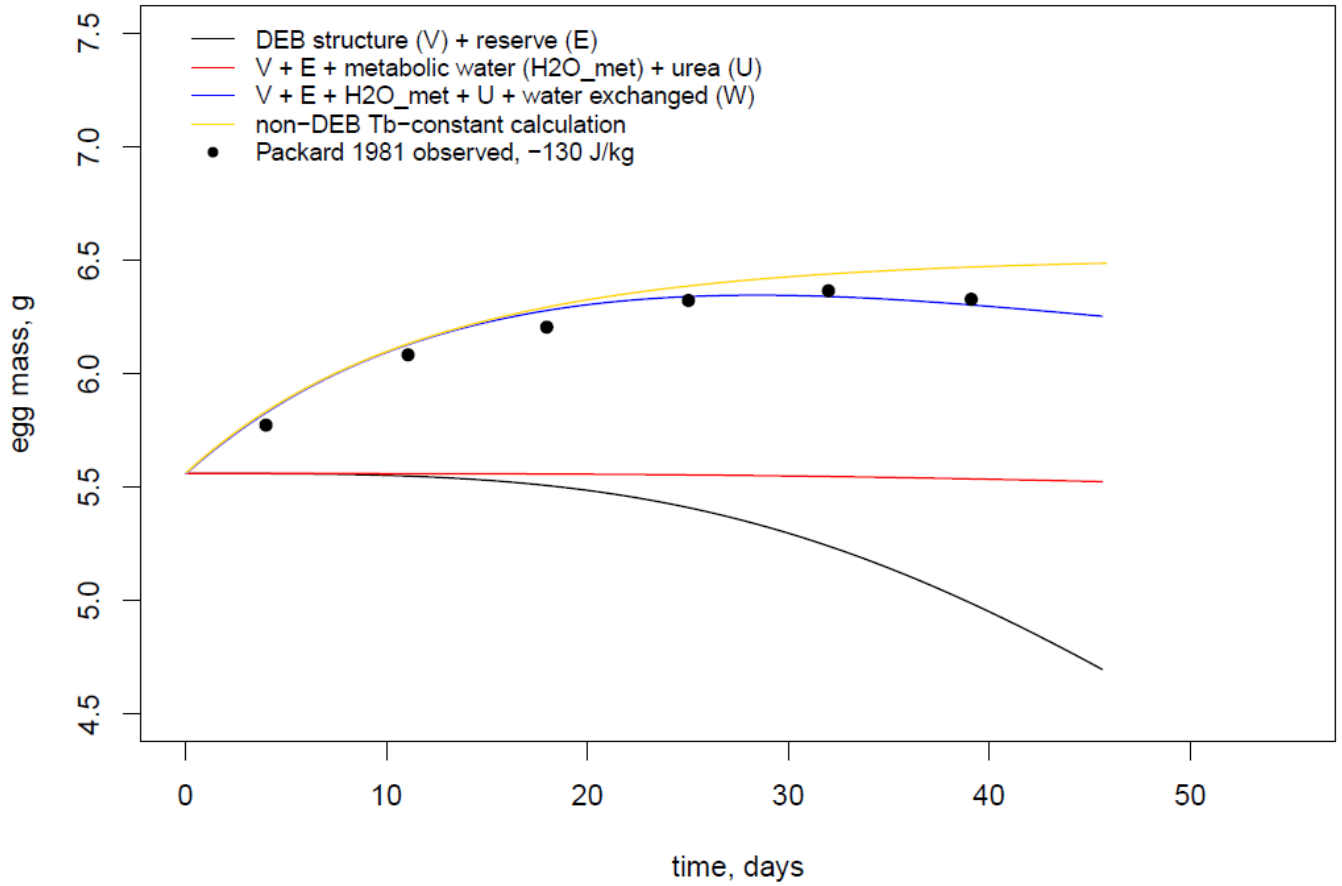
$$\mathbf{Y} = \begin{array}{c} \begin{matrix} A & G & D \end{matrix} \\ \begin{pmatrix} -y_{XE} & 0 & 0 \\ 1 & -1 & -1 \\ 0 & y_{VE} & 0 \\ y_{PE} & 0 & 0 \end{pmatrix} \end{array} \begin{matrix} X \\ E \\ V \\ P \end{matrix}$$

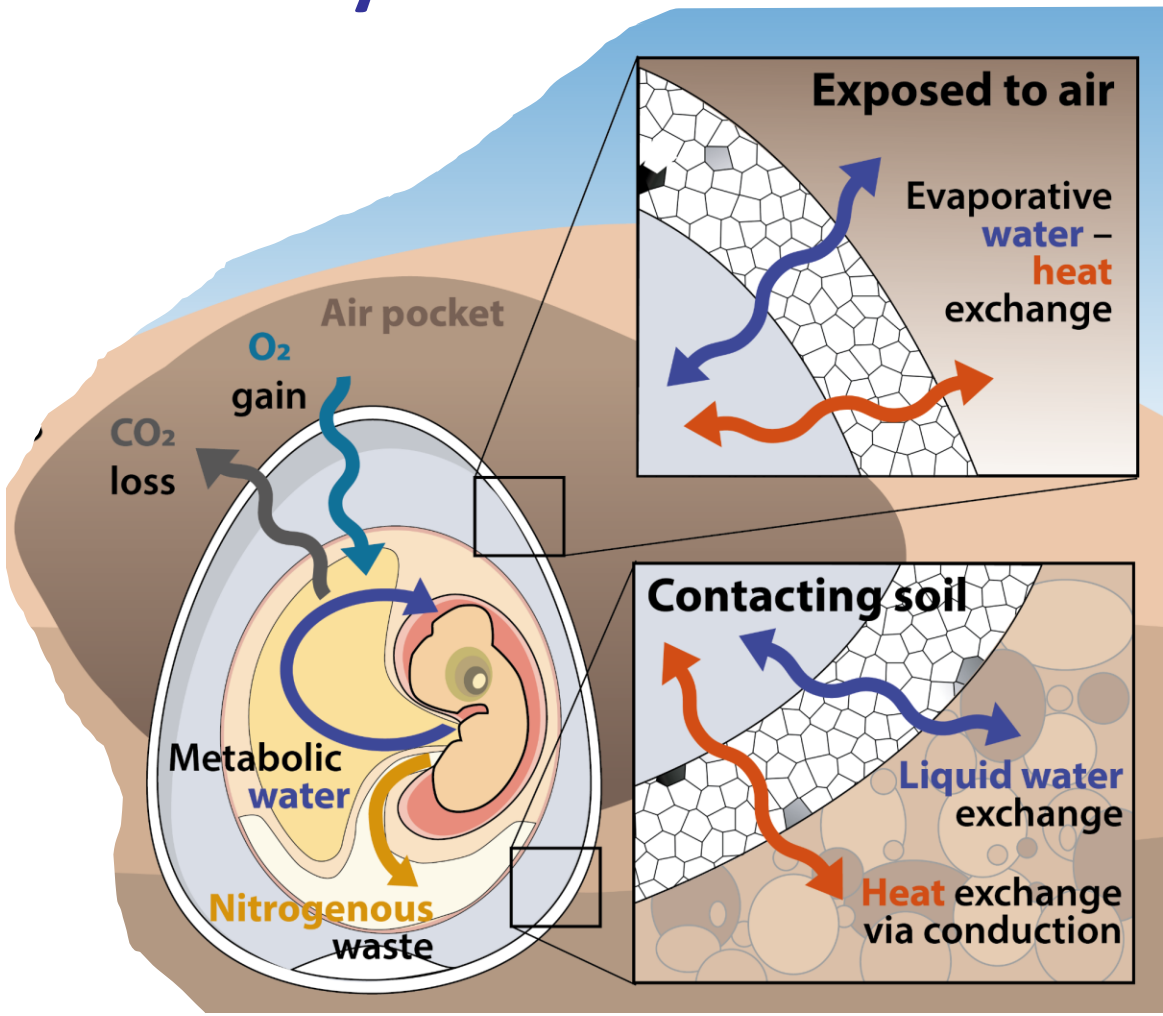
Integrating metabolic theory



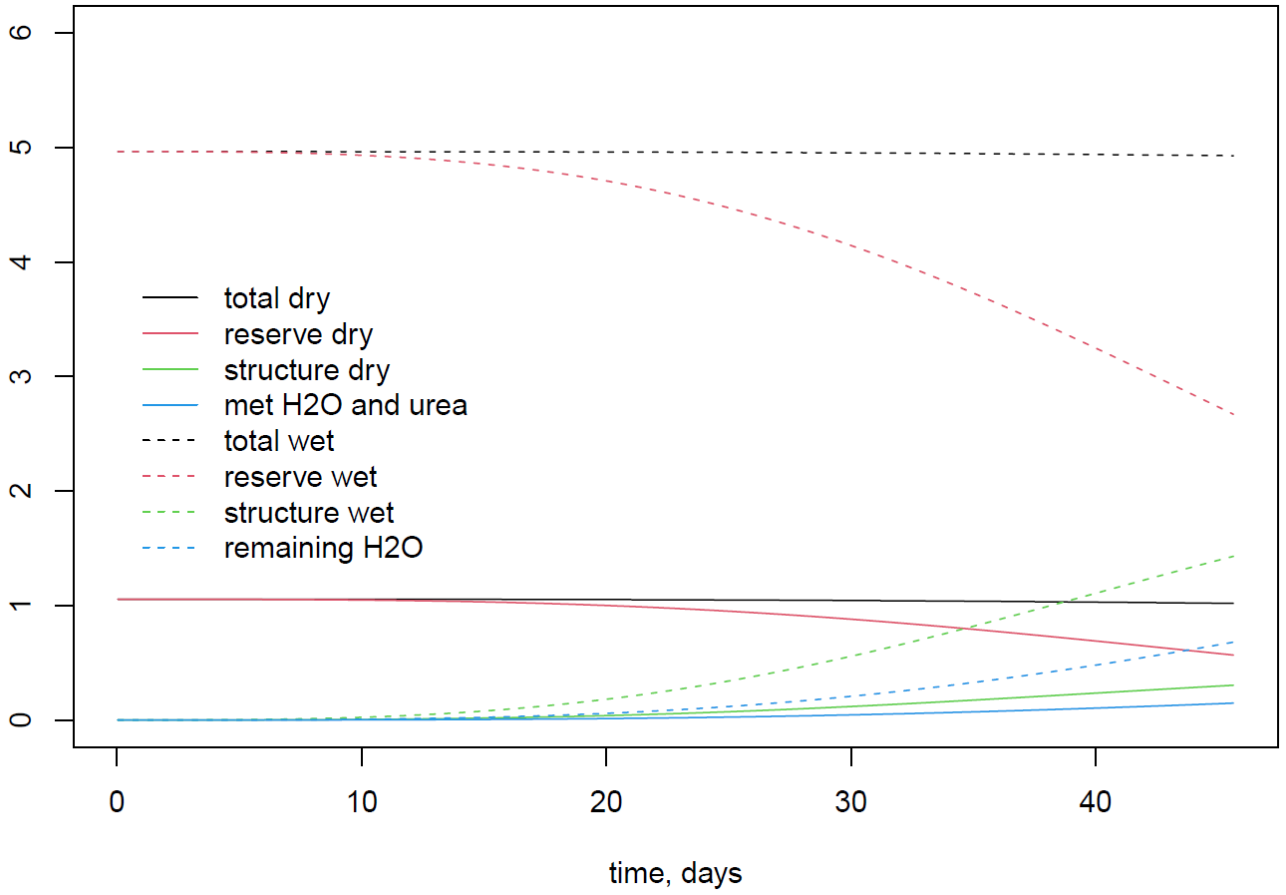


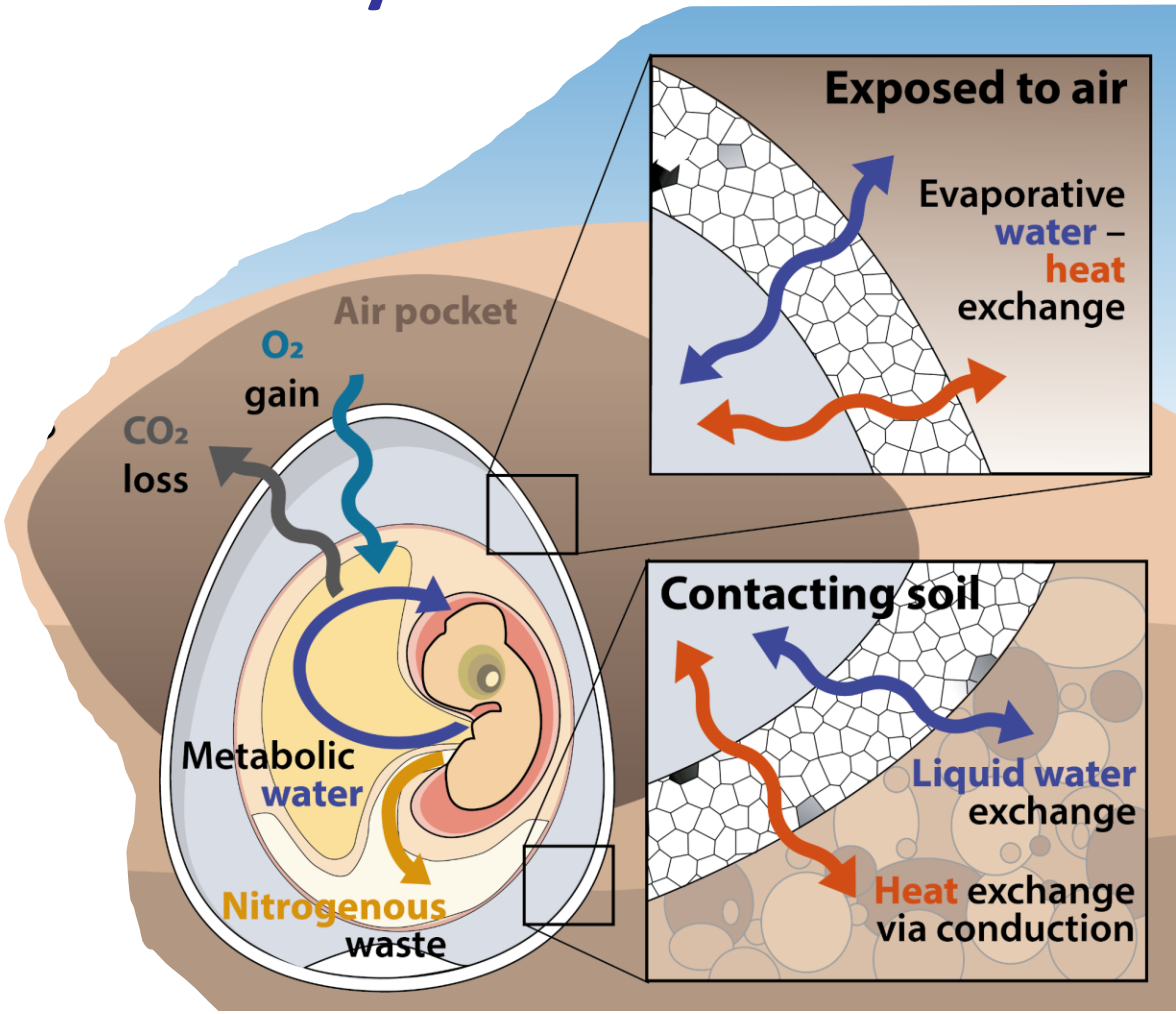
Integrating metabolic theory

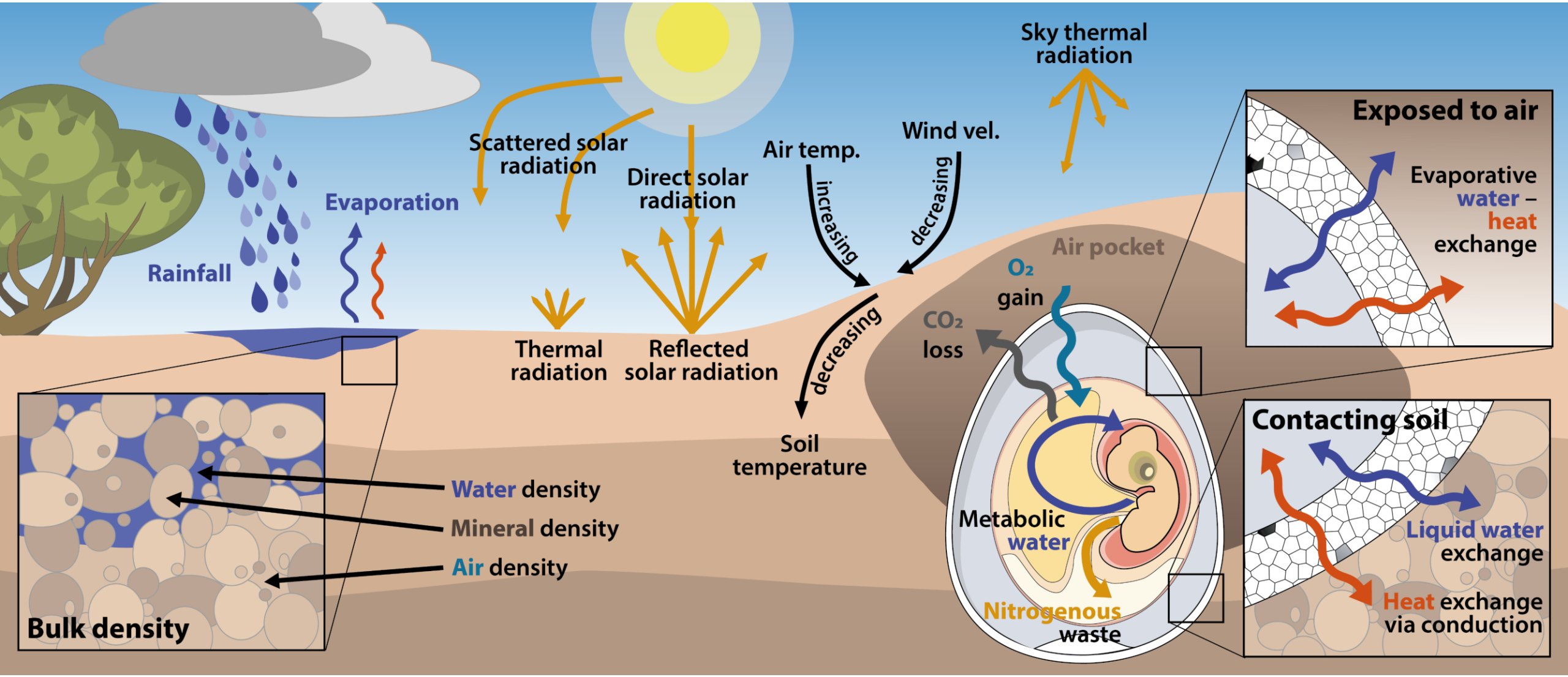




Integrating metabolic theory

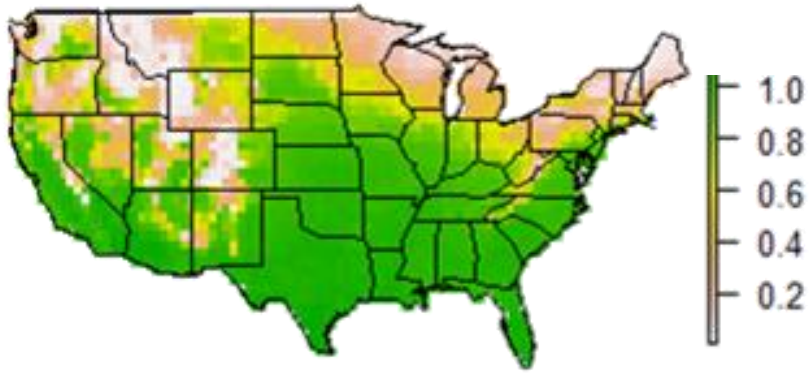





Sky thermal radiation
Scattered solar radiation
Direct solar radiation
Air temp.
increasing
Wind vel.
decreasing
Evaporation
Rainfall
Thermal radiation
Reflected solar radiation
decreasing
Soil temperature
Air pocket
O2 gain
CO2 loss
Metabolic water
Nitrogenous waste
Exposed to air
Evaporative water – heat exchange
Contacting soil
Liquid water exchange
Heat exchange via conduction
Water density
Mineral density
Air density
Bulk density

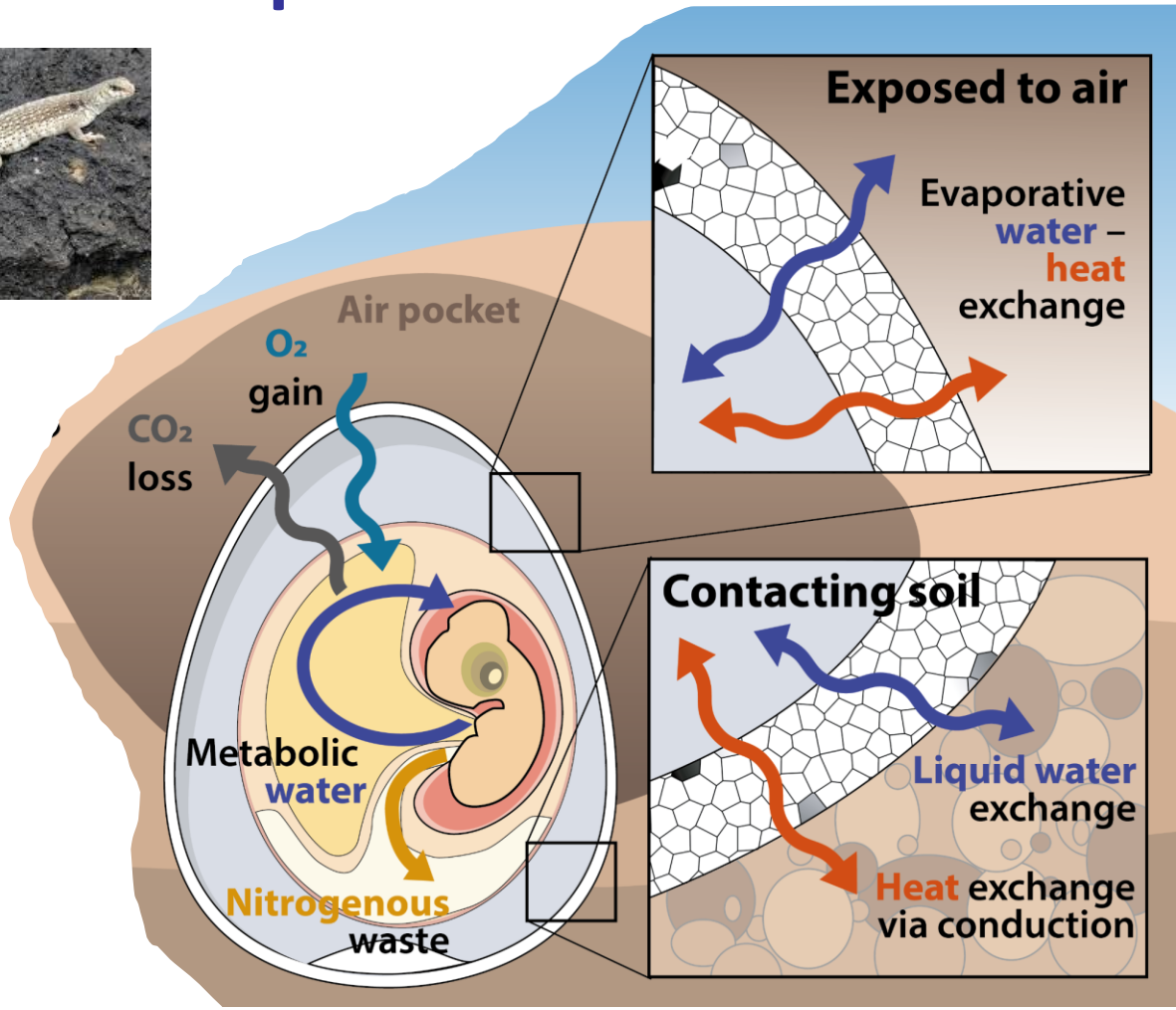
Mapping to the landscape

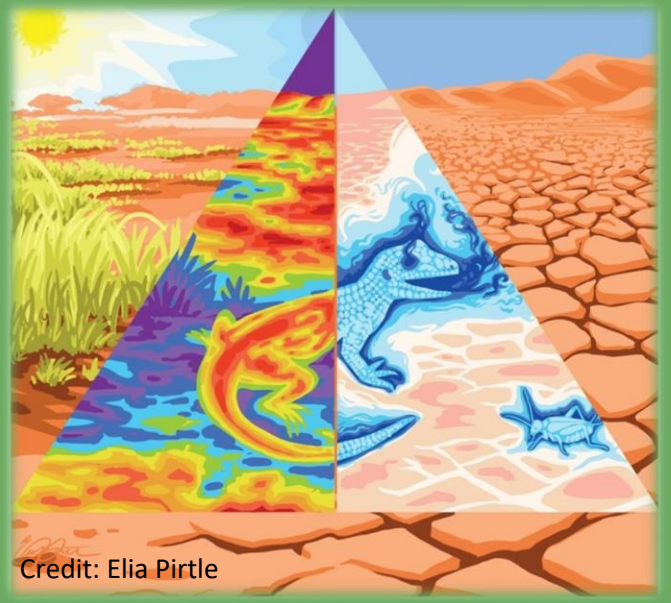
c) final development (fraction)



d) final mass (g)

Desert Iguana





Credit: Elia Pirtle

2.

Lizard distribution limits I

Life history variation and distribution limits

DEB 2025

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An example application in Mechanistic Niche Modelling

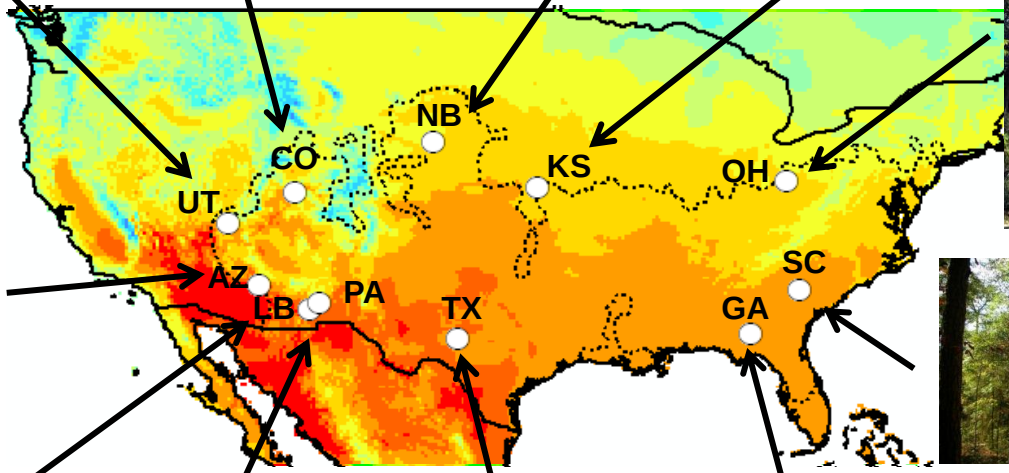
Life history variation in *Sceloporus undulatus*

Utah

Colorado

Nebraska

Kansas



Ohio

Arizona

South Carolina

Lordsburg

Pinos Altos

Texas

Georgia

Life history variation in *Sceloporus undulatus*

TABLE 6. COMPARISON OF LIFE HISTORY VARIABLES AMONG DIFFERENT POPULATIONS OF *Sceloporus undulatus*. Habitat classes follow Ferguson et al. (1980) and are C = canyonland, G = grassland and W = eastern woodland. Habitat abbreviations are: T = terrestrial, A = arboreal, S = saxicolous and T/A = semi-arboreal. Sources: (1) Tinkle, 1972 (2) Tinkle and Ballinger, 1972 (3) Vinegar, 1975a, b (4) Ferguson et al., 1980 (5) Ballinger et al., 1981 (6) Crenshaw, 1965.

	Arizona (this study)	Utah[1]	Colorado[2]	Pinos Altos[3] New Mexico	Lorsdburg[3] New Mexico	Kansas[4]	Nebraska[5]	Texas[2]	Ohio[2]	South[2] Carolina	Georgia[6]
Habitat type	C	C	C	C	G	G	G	G	W	W	W
Habitat	T	A	S	S	T	T	T	T/A	T/A	T/A	A
Mean clutch size	8.3	6.3	7.9	7.2	9.9	7.0	5.5	9.5	11.8	7.4	7.6
Clutch frequency	3	3	2	2–3	4	1–2	2	3	2	3	2–3
Egg wet mass (g)	.29	.36	.42	.29	.24	.26	.23	.22	.35	.33	—
RCM	.22	.21	.23	.21	.21	.28	.33	.27	.25	.23	—
Hatchling SVL (mm)	25–29	25	27–30	—	25	23–24	—	21–23	24–26	21–25	21–23
Minimum SVL of mature females	60	58	58	53	54	47	45	47	66	55	52
Average SVL of adult females	65	69	70	63	68	57	55	57	75	63	62
Average age at maturity (mo)	11.5	22.8	20.5	18	12	12	9.5	12	20	12	12
Survival to first reproduction	.07	.05	.11	.02	.03	.10	—	.06	.03	.11	—
Average survival of adult females	.24	.48	.37	.32	.20	.27	—	.11	.44	.49	.07
Mean density (animals/ha)	29 (8–36)	35	14	35 (26–42)	9 (8–10)	48	—	2	22	8	—

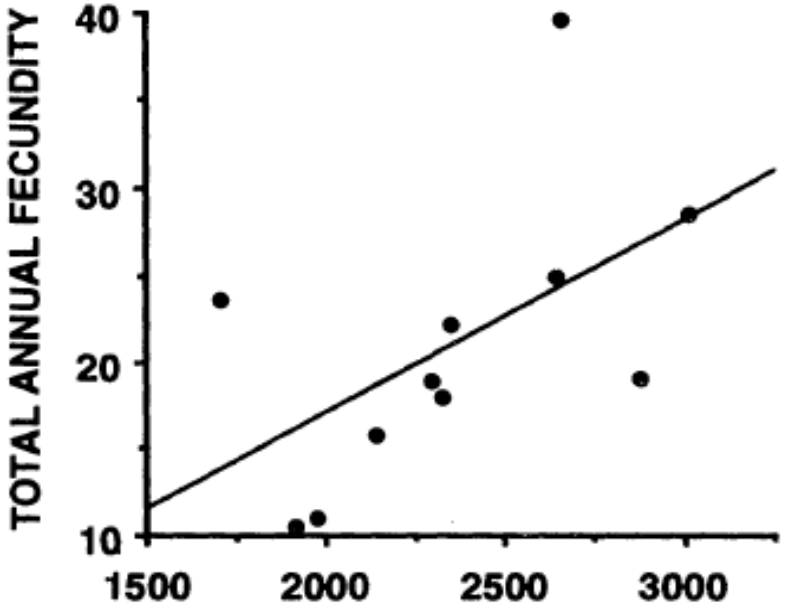
Tinkle D.W. & Dunham A.E. (1986). *Copeia, 1986, 1-18.*

Environmental effects on life history

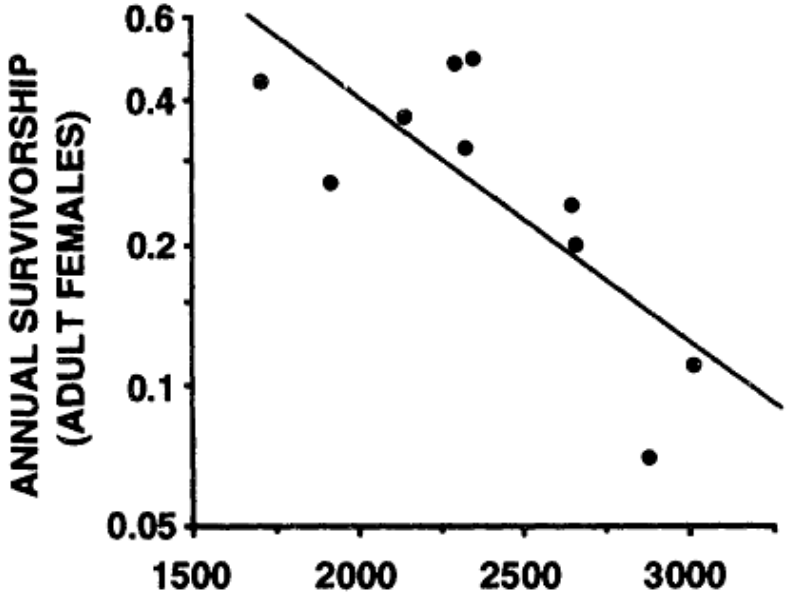
Vol. 142, No. 2 The American Naturalist August 1993

TEMPERATURE, ACTIVITY, AND LIZARD LIFE HISTORIES

STEPHEN C. ADOLPH AND WARREN P. PORTER



annual activity hours

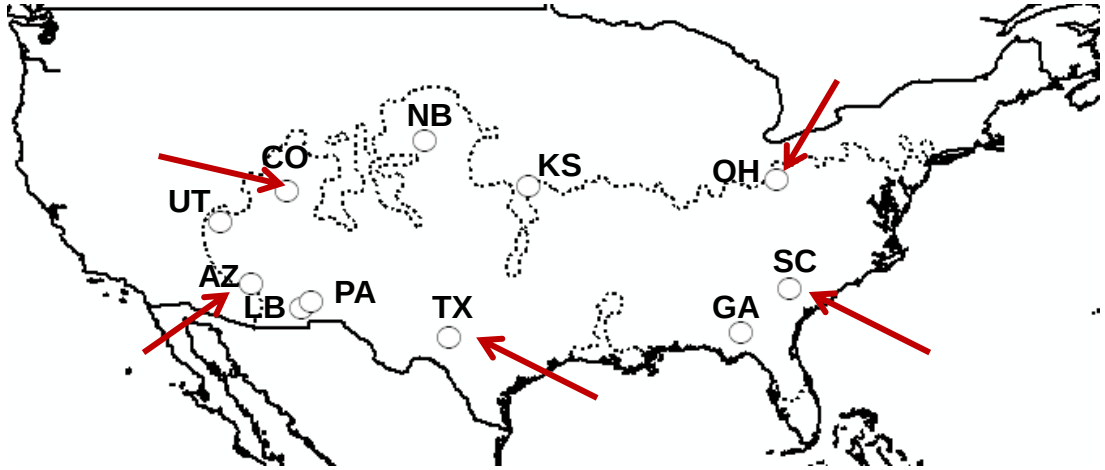


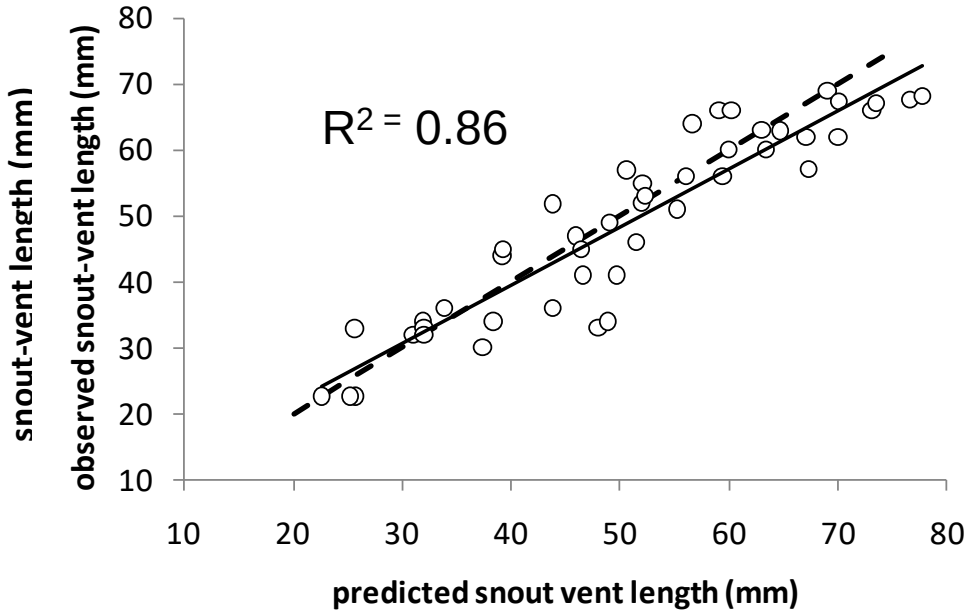
annual activity hours

Example 3: Eastern Fence Lizard

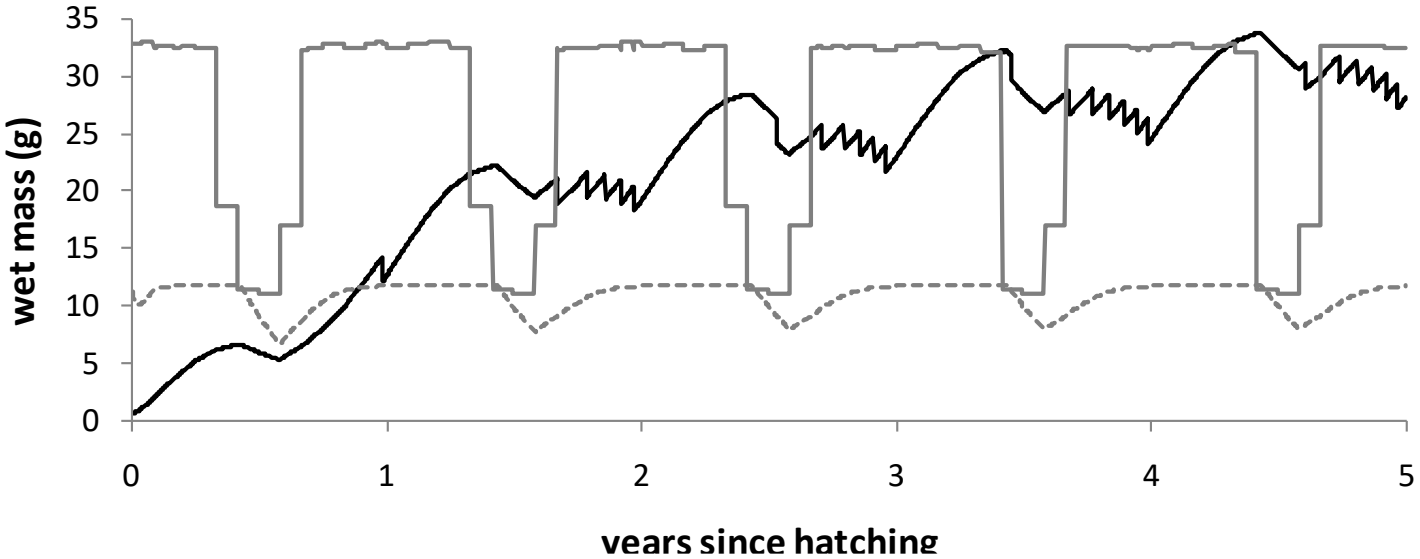
A year in the life of the Fence Lizard in Utah

Predicting field growth rates with DEB theory

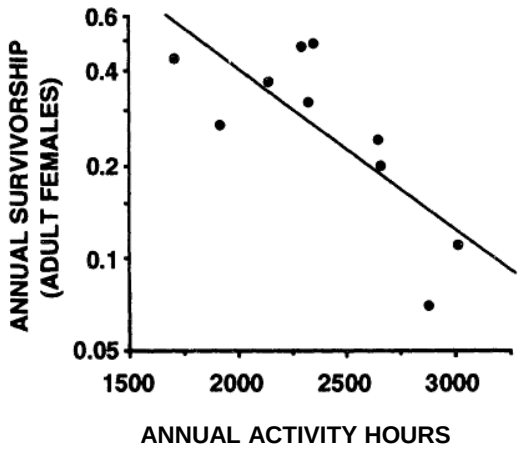




DEB predictions of timing of reproduction

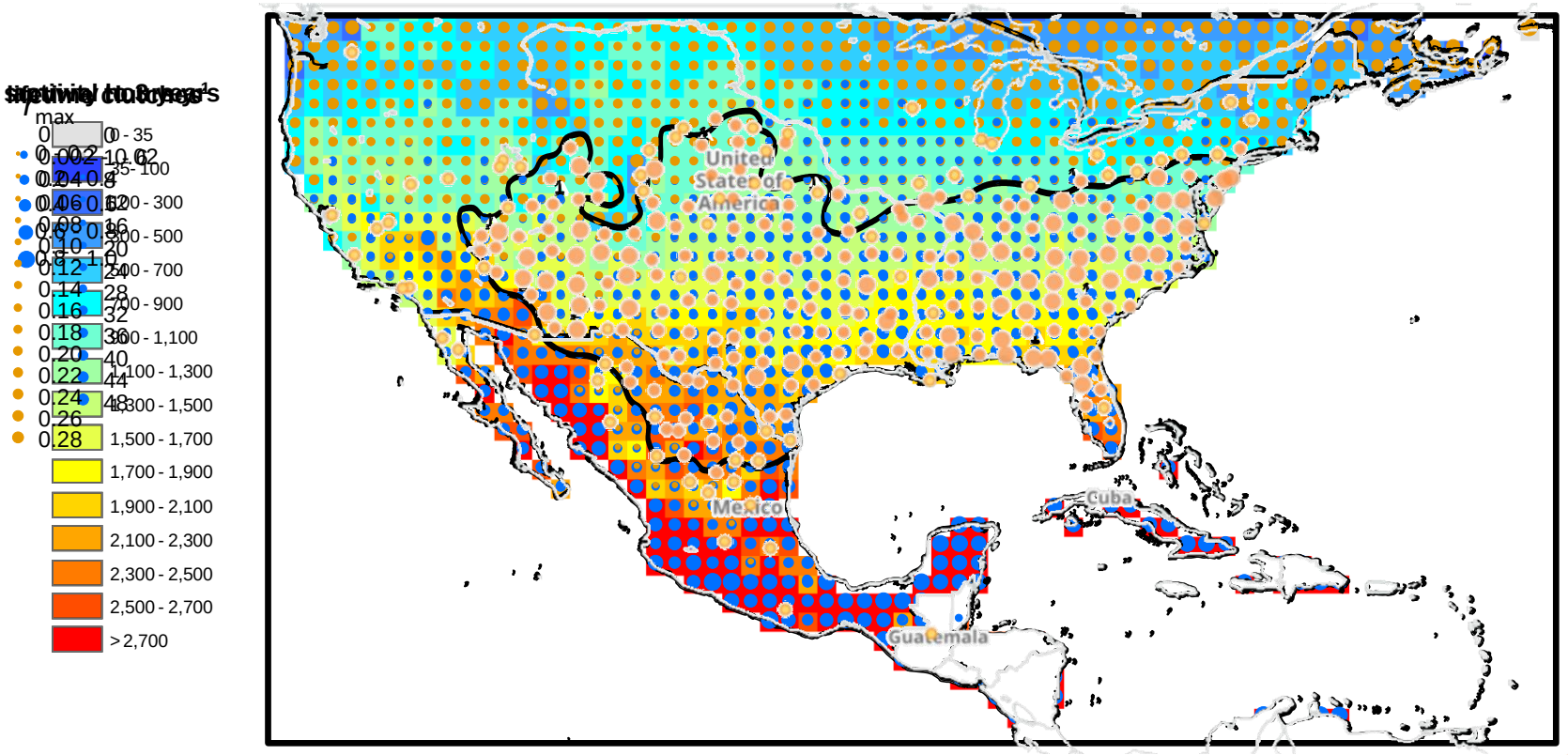


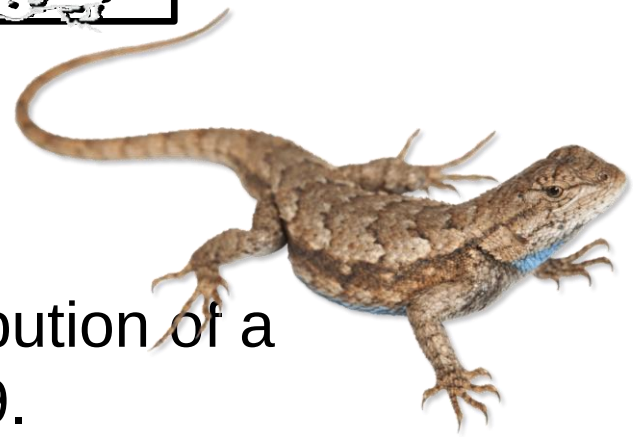
— Wet mass
- - - Reserve Density
— Body Temperature



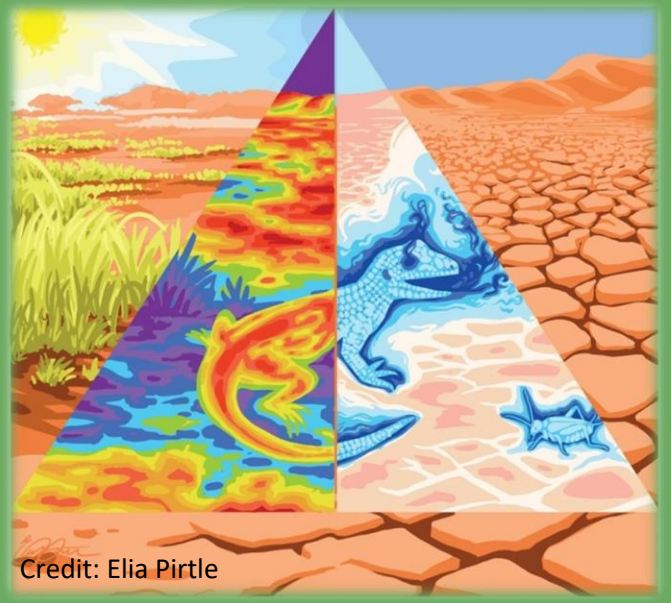
x	lx	mx	lxmx
0	1.00	0.0	0.000
1	0.23	3.2	0.732
2	0.05	15.8	0.760
3	0.01	22.0	0.209
4	0.00	22.0	0.041
		R0	**1.74**
		r_{max}	**0.376**

Predicting geographic range





Kearney, M. (2012). Metabolic theory, life history and the distribution of a terrestrial ectotherm. *Functional Ecology*, 26, 167–179.



Credit: Elia Pirtle

3.

Lizard distribution limits II

What are the relative roles of temperature and water?

DEB 2025

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University of Crete, Heraklion, Greece

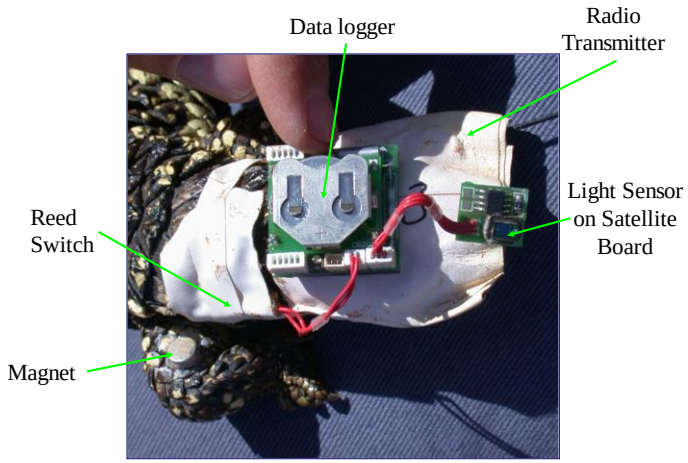
The Sleepy Lizard *Tiliqua rugosa*

Ecological Monographs, 88(4), 2018, pp. 672–693

Field tests of a general ectotherm niche model show how water can limit lizard activity and distribution

MICHAEL R. KEARNEY,[1,7] SUZANNE L. MUNNS,[2] DANAE MOORE,[3,4] MATTHEW MALISHEV,[1,5] AND C. MICHAEL BULL[6]

Thermal biology: the ‘waddleometer’



Prof. Mike Bull

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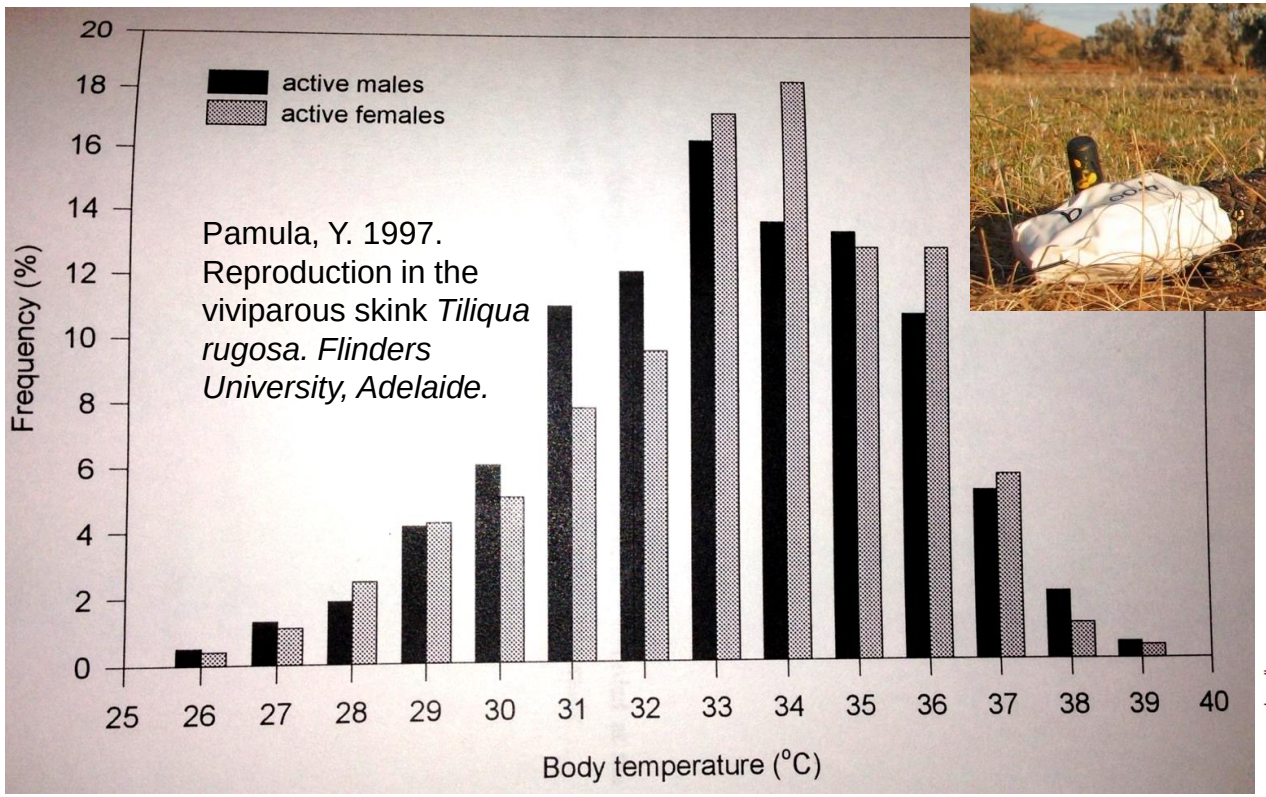
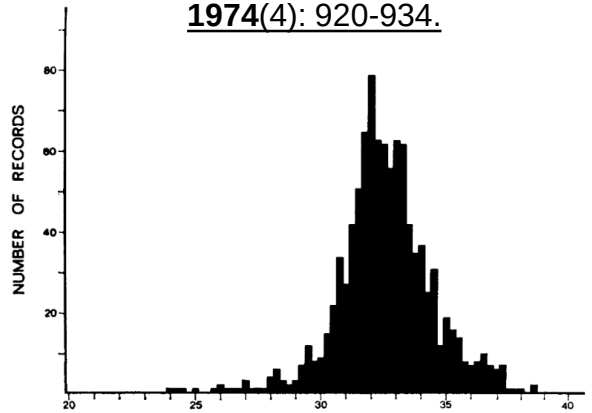
Thermal biology: the ‘waddleometer’

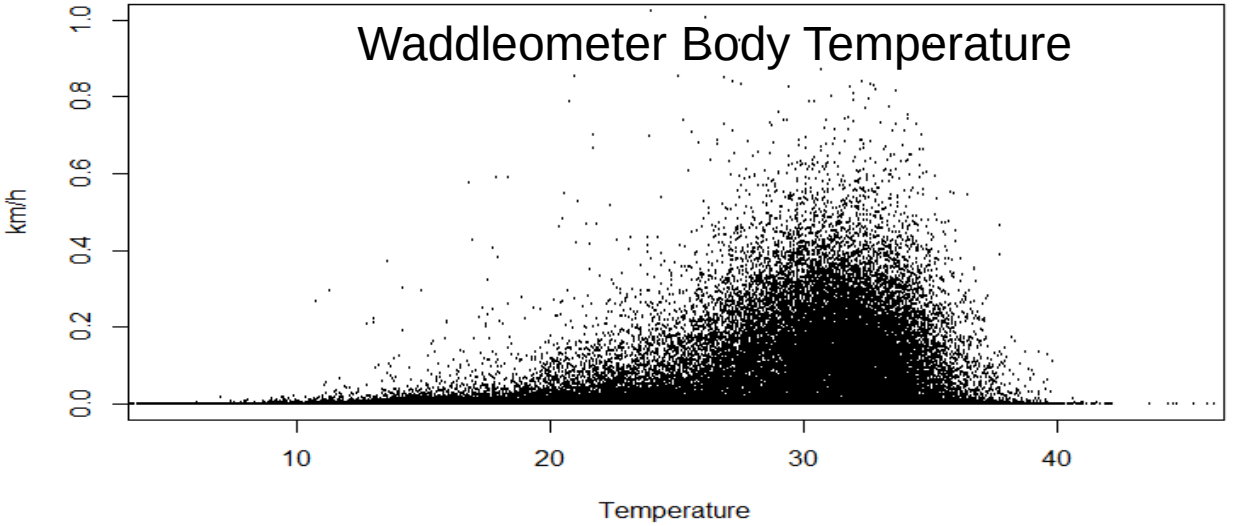
Field Active Body Temperature



Lab Gradient Body Temperature

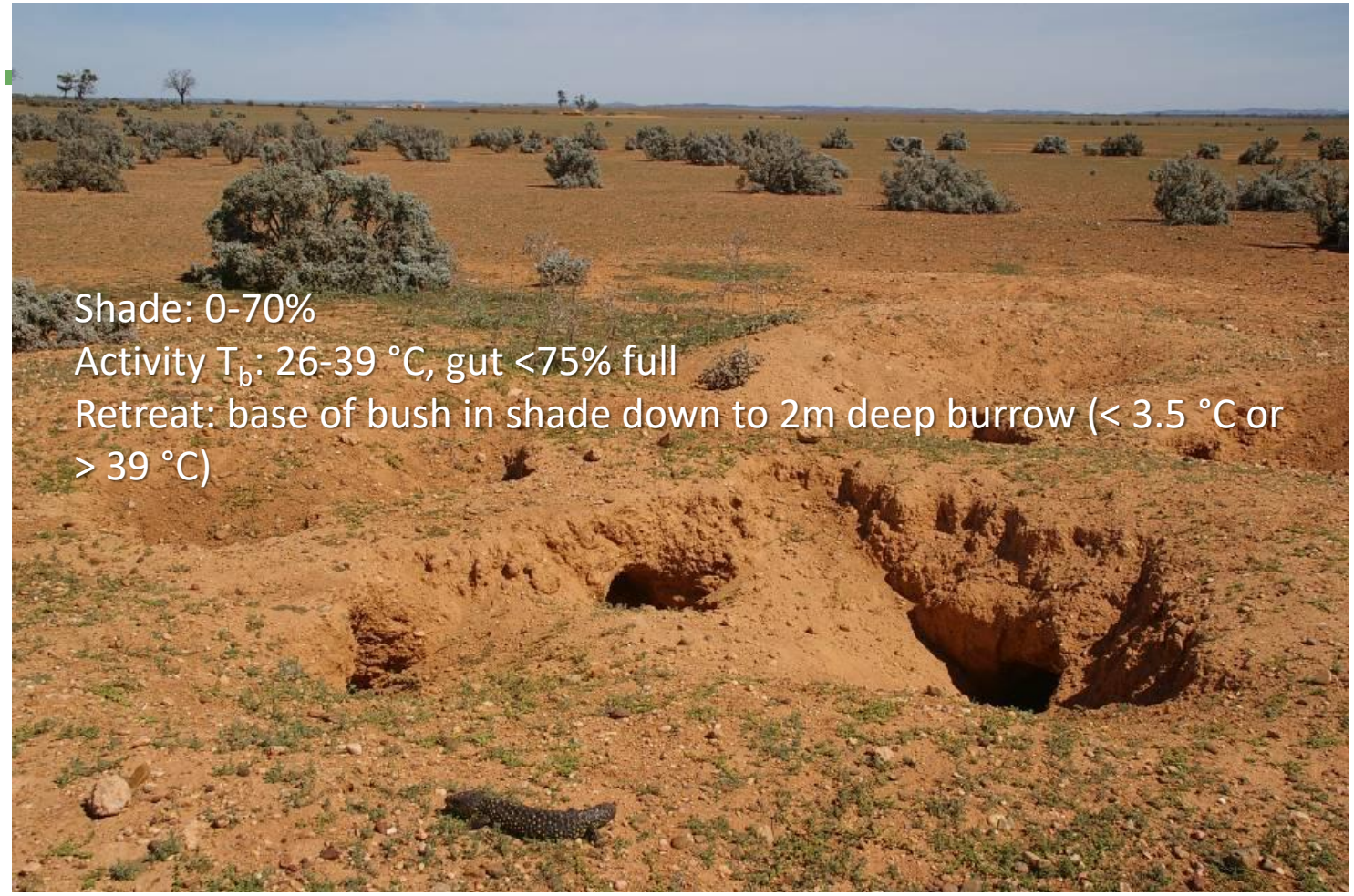
Wilson (1974). Copeia **1974**(4): 920-934.





Thermal biology: modelling with NicheMapR

SLEEPY LIZARD



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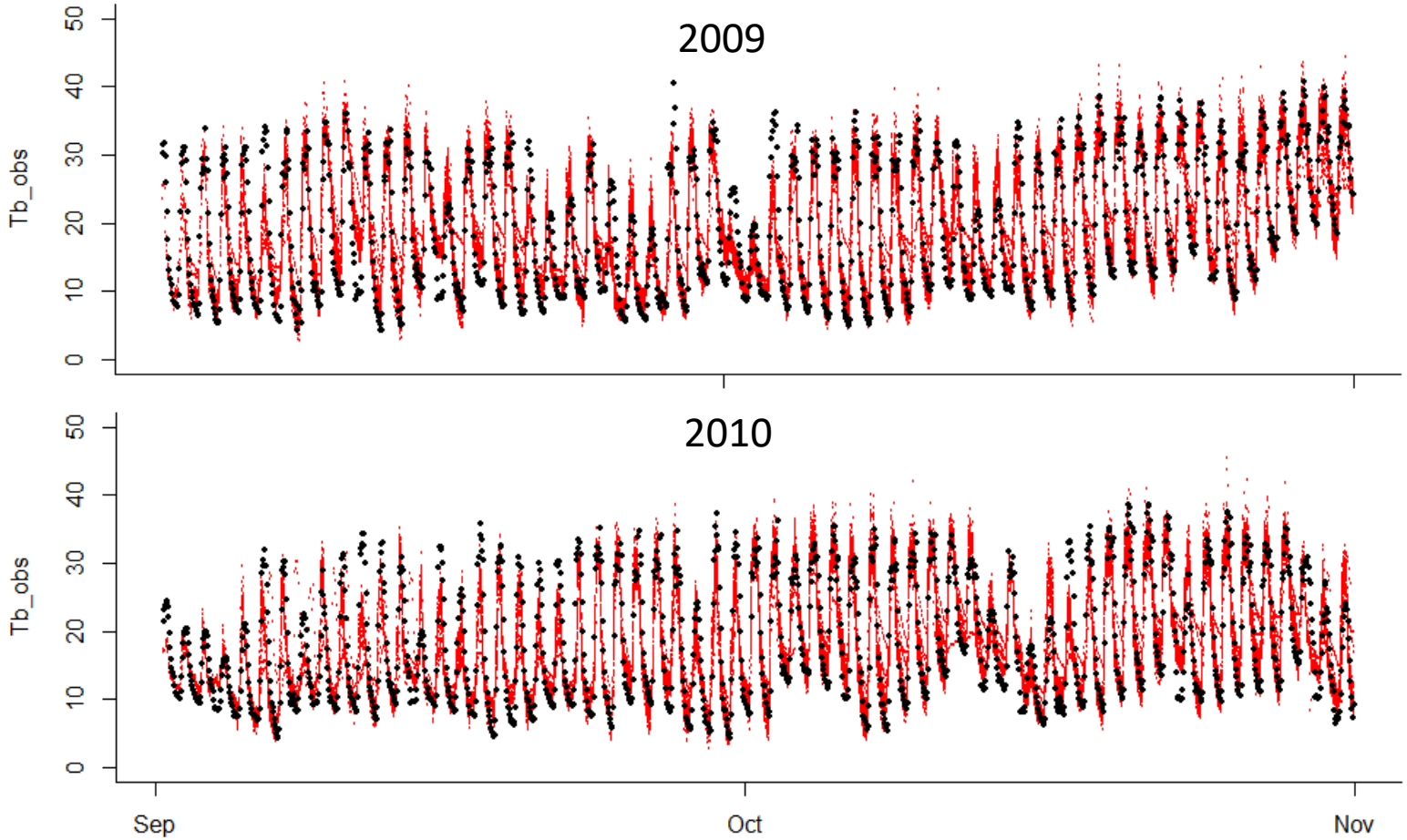
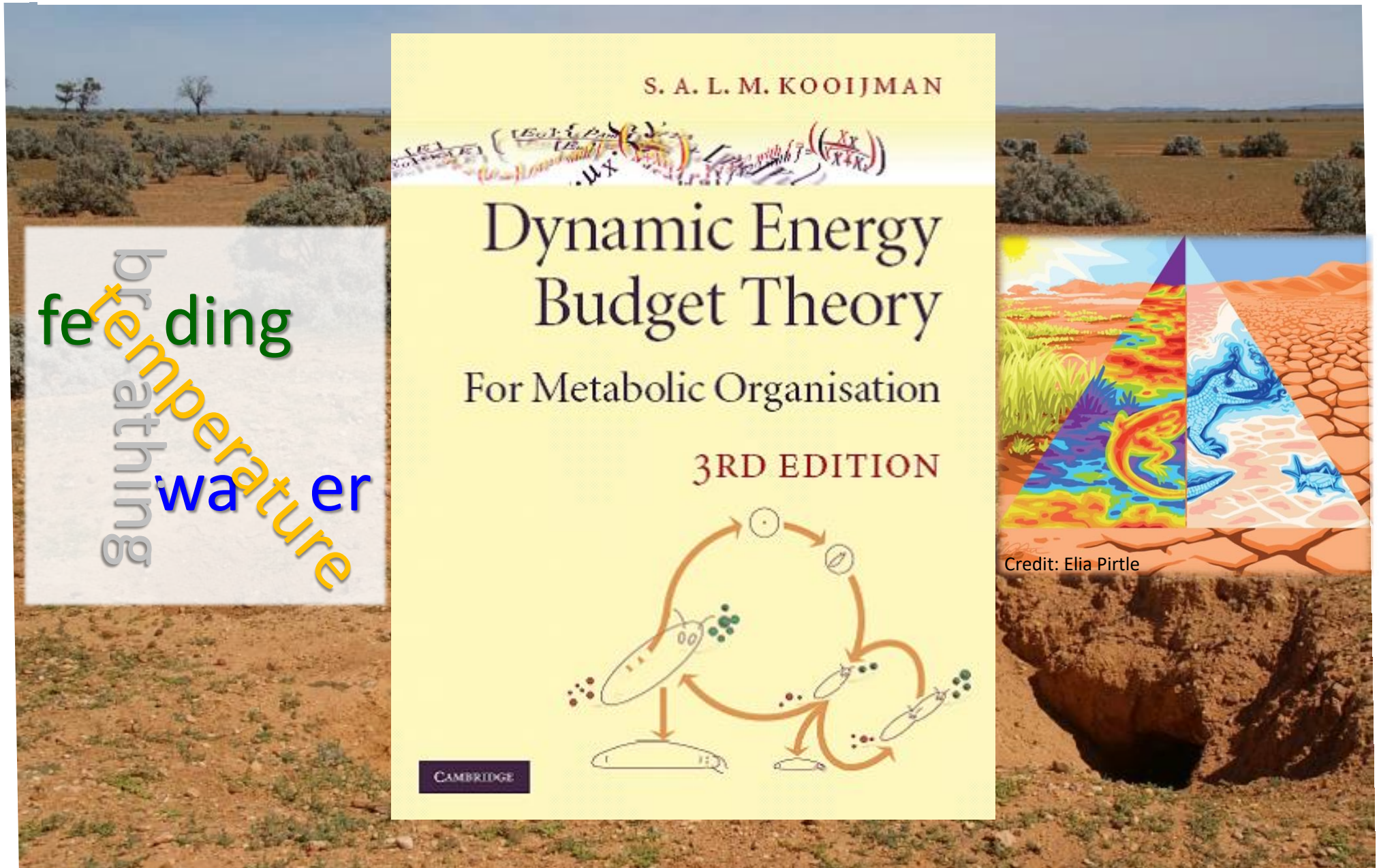
Thermal biology: modelling with NicheMapR

Prof. Mike Bull

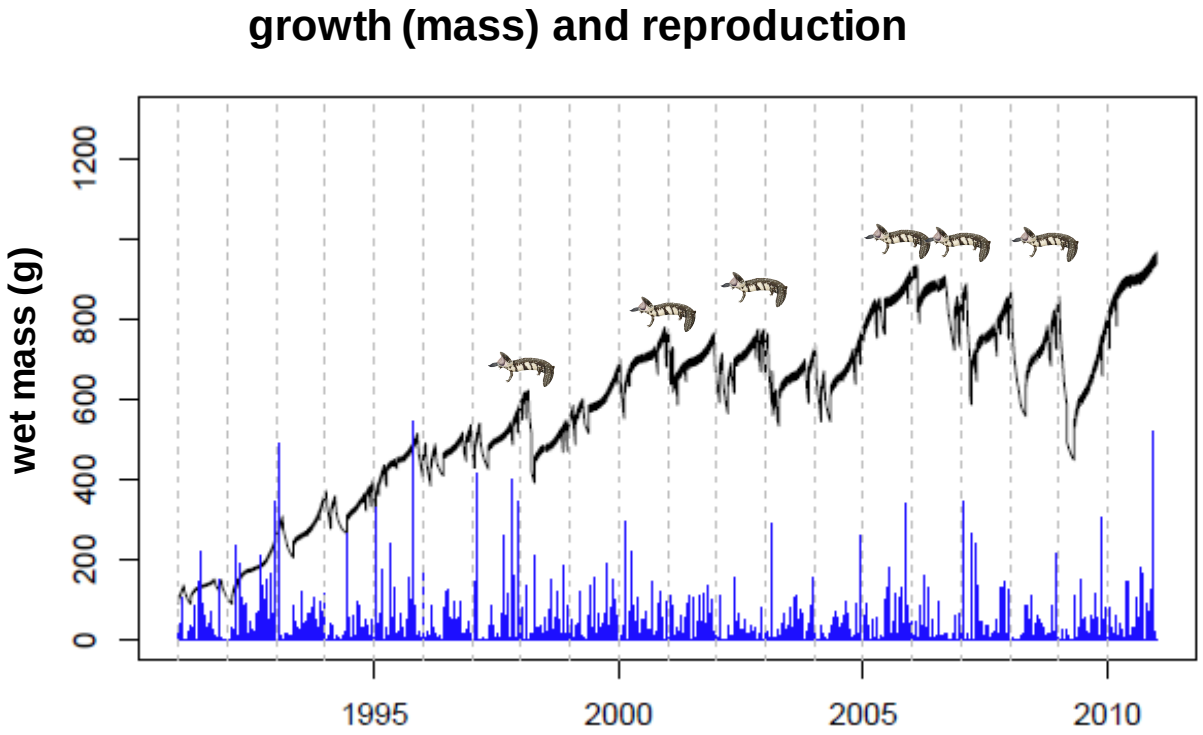


Incorporating water and energetics with DEB



Incorporating water and energetics with DEB

Suzy Munns
James Cook
University



Food Structure Reserve Faeces

$$\begin{pmatrix} n_{CX} & n_{CV} & n_{CE} & n_{CP} \\ n_{HX} & n_{HV} & n_{HE} & n_{HP} \\ n_{OX} & n_{OV} & n_{OE} & n_{OP} \\ n_{NX} & n_{NV} & n_{NE} & n_{NP} \end{pmatrix} \begin{pmatrix} j_X \\ j_V \\ j_E + j_{E_R} \\ j_P \end{pmatrix}$$

Food
Structure
Reserve
Faeces

$=$

CO_2 H_2O O_2 N waste

$$\begin{pmatrix} 1 & 0 & 0 & n_{CN} \\ 0 & 2 & 0 & n_{HN} \\ 2 & 1 & 2 & n_{ON} \\ 0 & 0 & 0 & n_{NN} \end{pmatrix} \begin{pmatrix} j_C \\ j_H \\ j_O \\ j_N \end{pmatrix}$$

CO_2
H_2O
O2
N waste

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Incorporating water and energetics with DEB

p = heat flux
J = mass flux
X = food
H = water
I = ingested
P = product (faeces)
U = urinated
G = growth
R = reproduction
S = stored
O_2 = oxygen
CO_2 = carbon dioxide
N = nitrogenous waste
MET = 'metabolism'
EVAP = evaporation
SOLAR = solar radiation
IR = infrared radiation
CONV = convection
COND = conduction

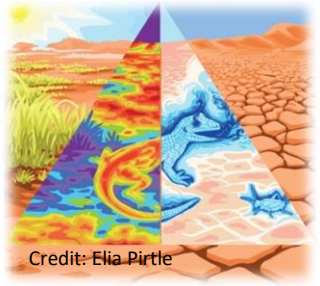
$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \left(J \xrightarrow{p} MET\right) + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P}$$

$$= p_{IR,out} + J_{CO2,MET} + J_{N,MET} + p_{CONV} + J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \left(J \xrightarrow{p} EVAP\right) + p_{COND}$$

heat

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$

feeding
breathing
temperature
water


Credit: Elia Pirtle

Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

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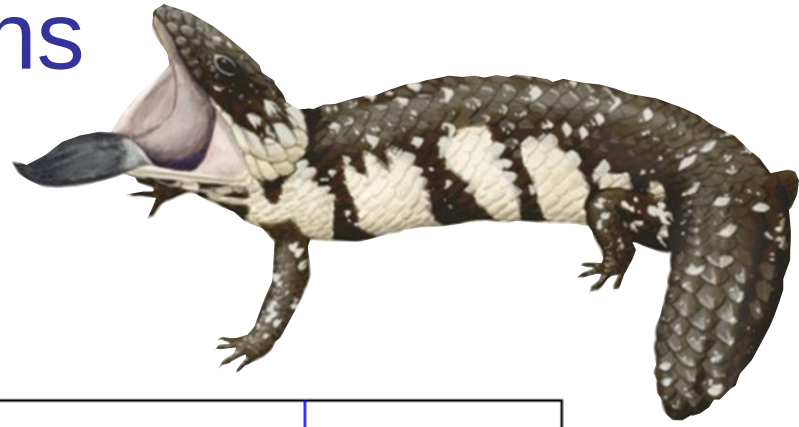
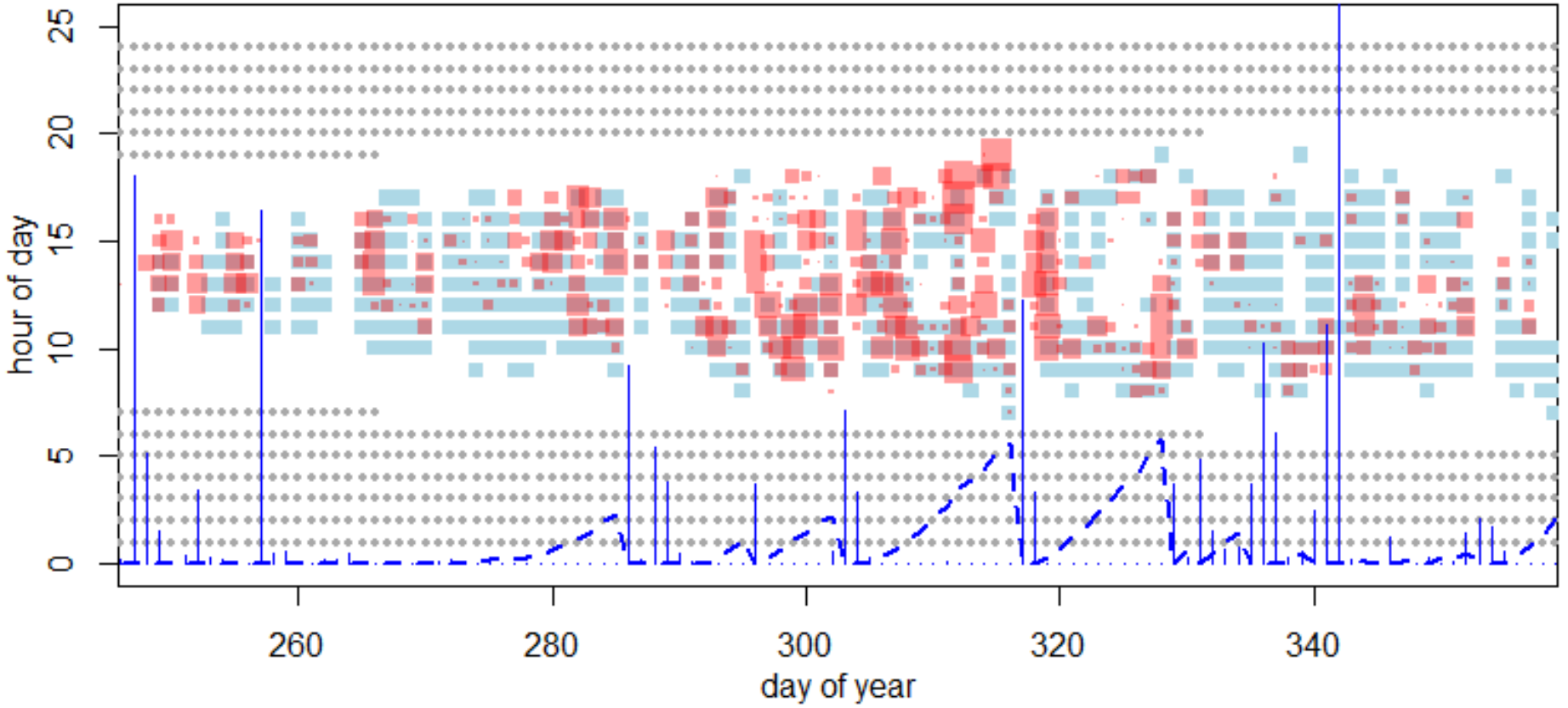
Predicting activity patterns

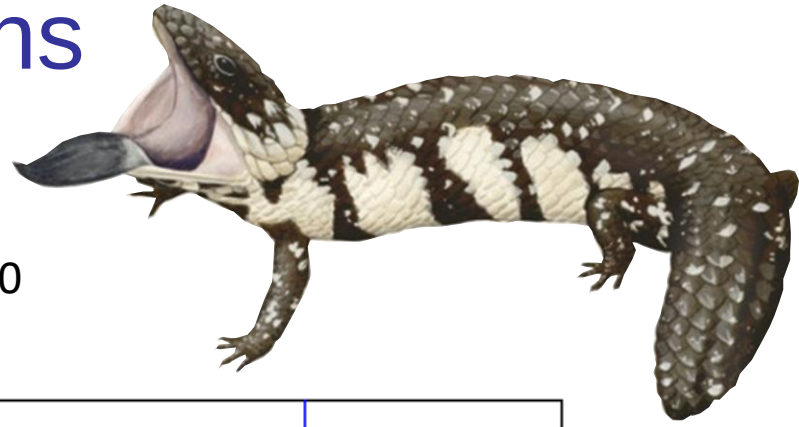


Male 11885 observed activity vs. potential foraging, 2010



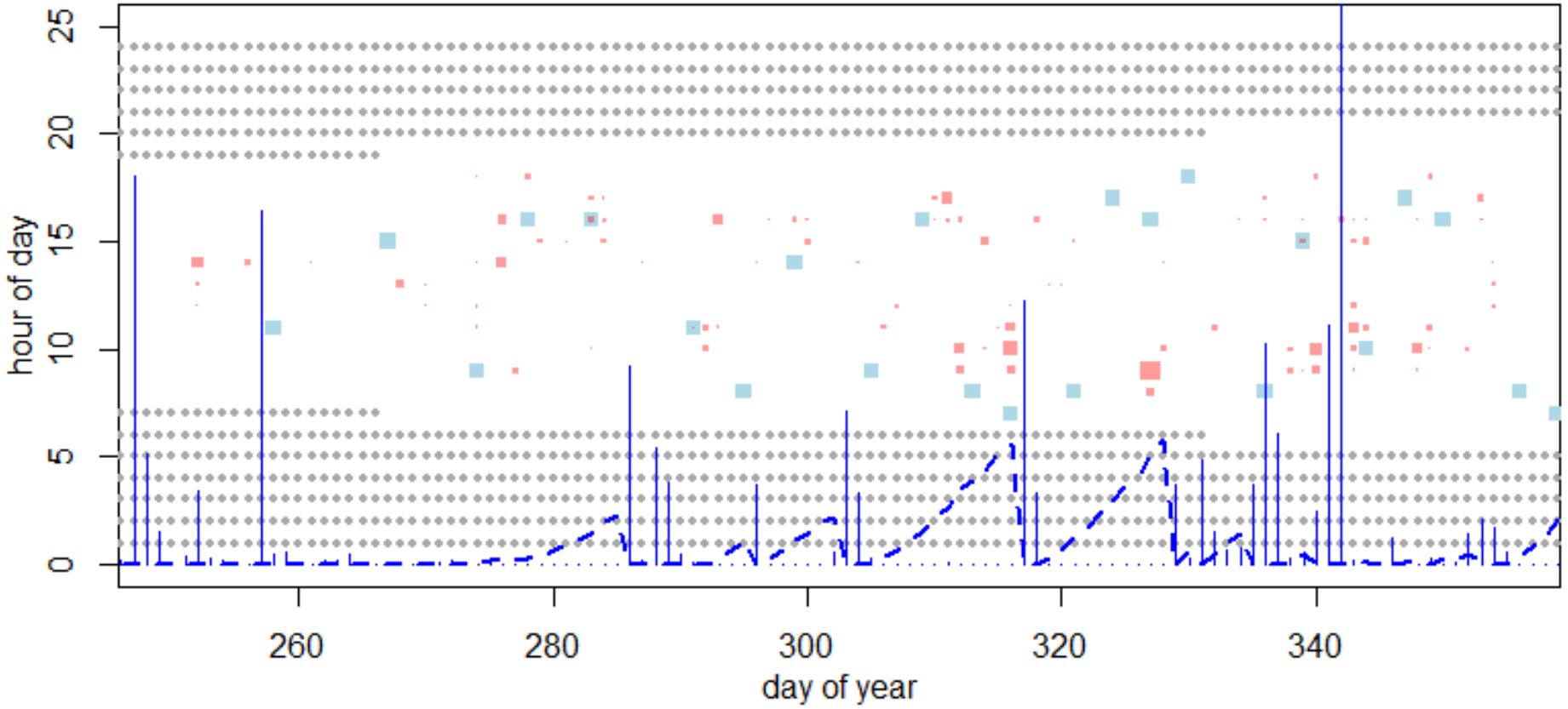
Kearney et al. 2018. Field tests of a general ectotherm niche model show how water can limit lizard activity and distribution. Ecological Monographs 88:672–693.

Predicting activity patterns



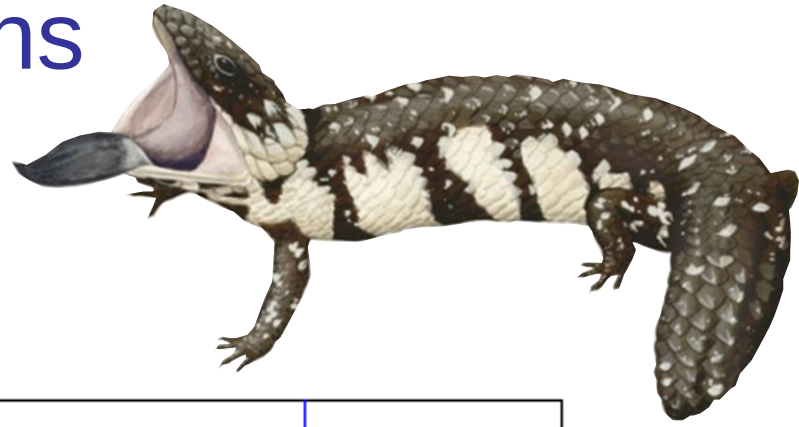
SLEEPY LIZARD

Female 11533 observed activity vs. modelled feeding events, 2010



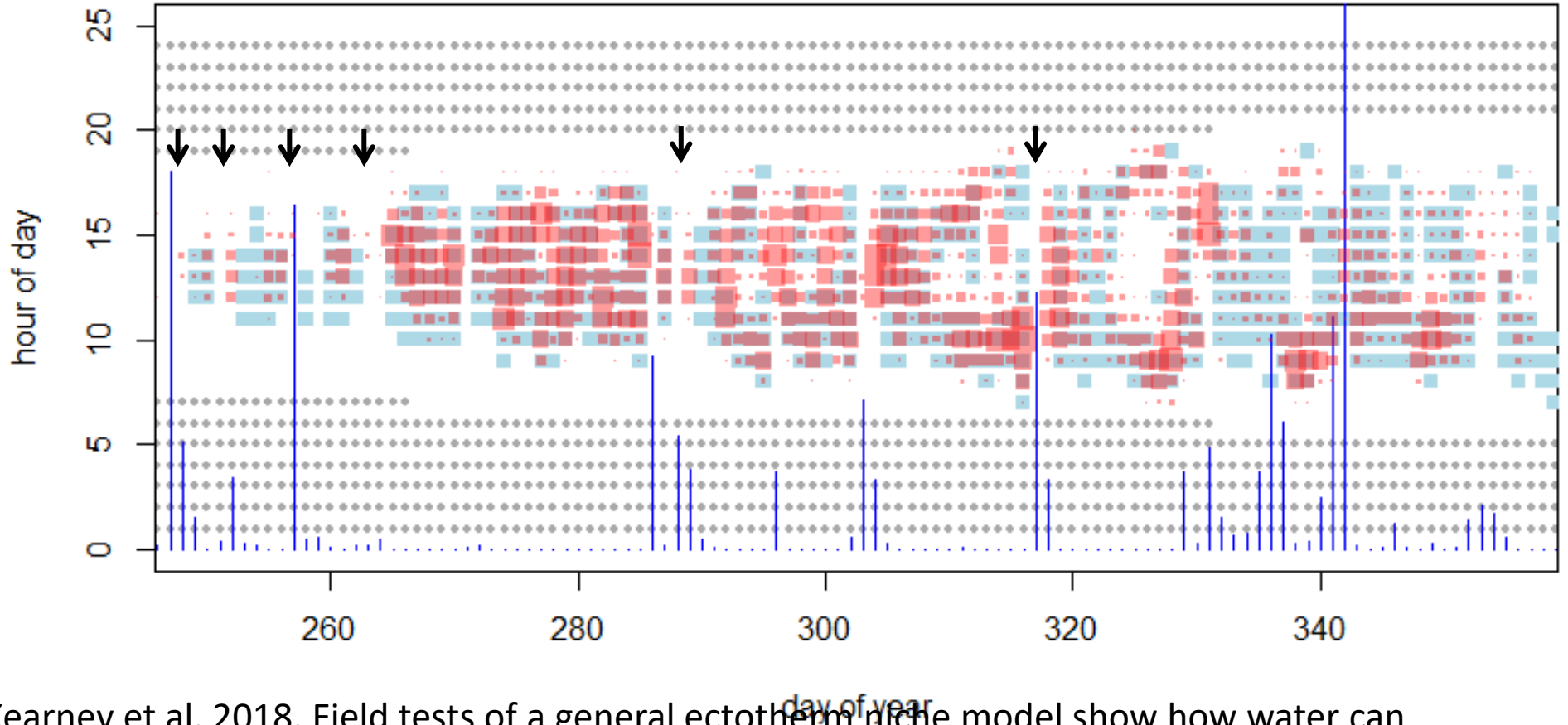
Kearney et al. 2018. Field tests of a general ectotherm niche model show how water can limit lizard activity and distribution. Ecological Monographs 88:672–693.

Predicting activity patterns



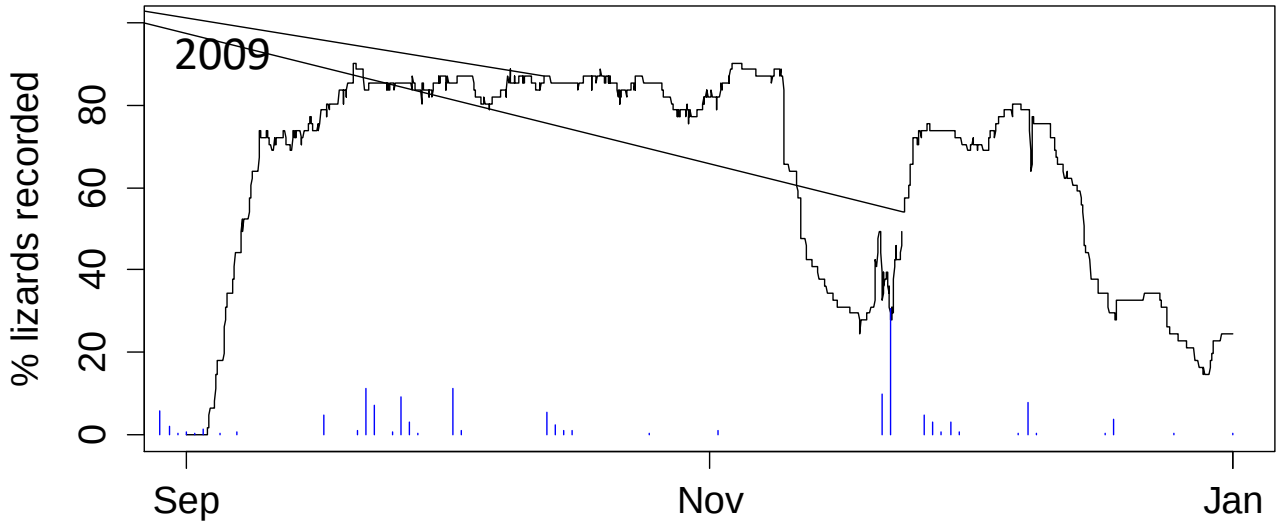
SLEEPY LIZARD

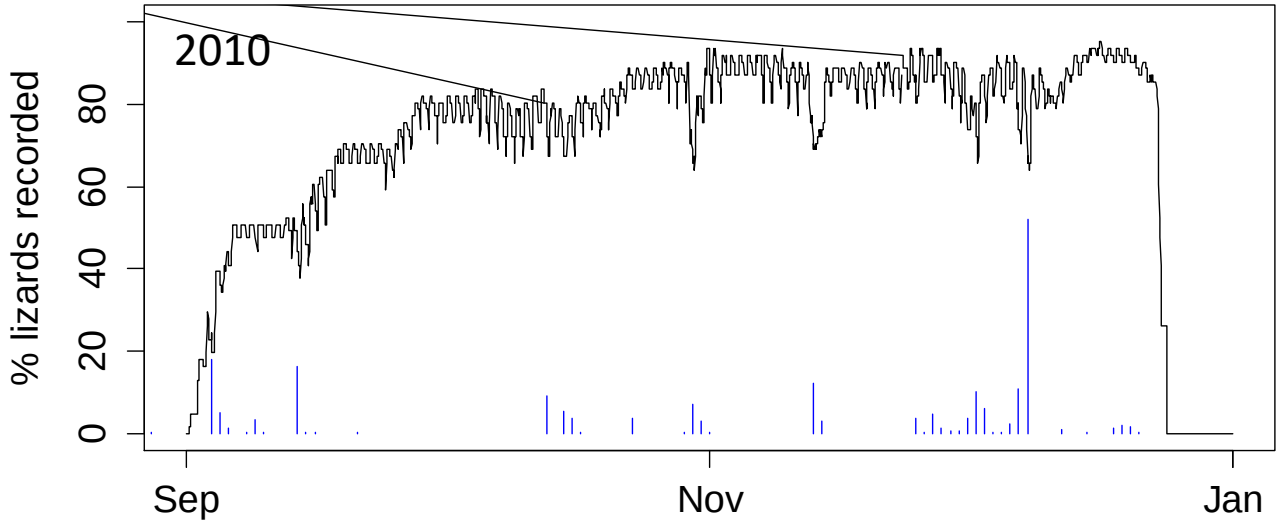
All observed activity vs. potential foraging, 2010



Kearney et al. 2018. Field tests of a general ectotherm niche model show how water can limit lizard activity and distribution. Ecological Monographs 88:672–693.

Predicting activity patterns





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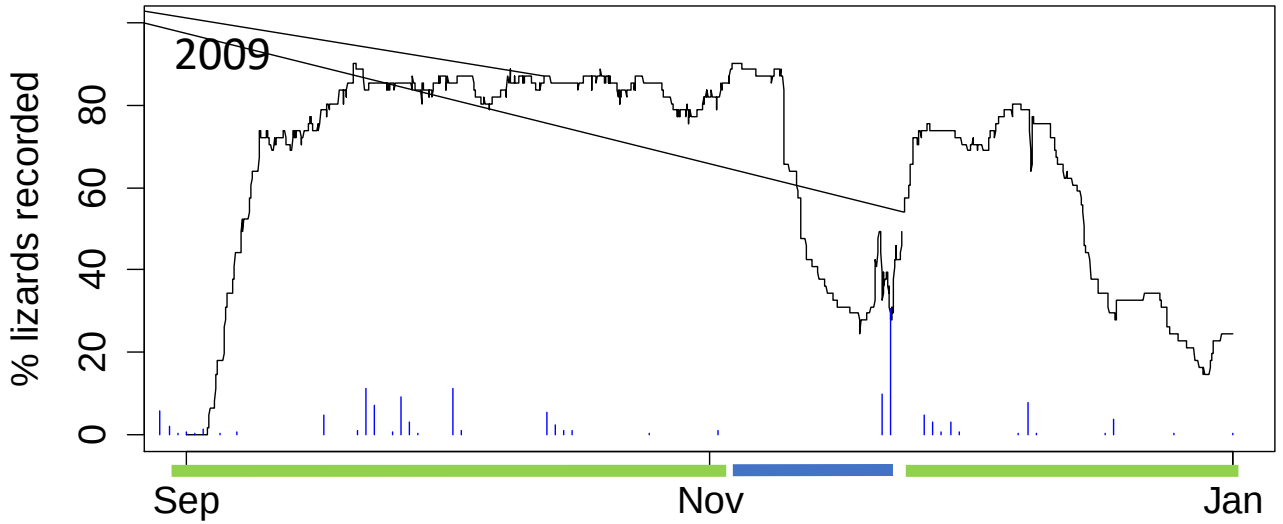
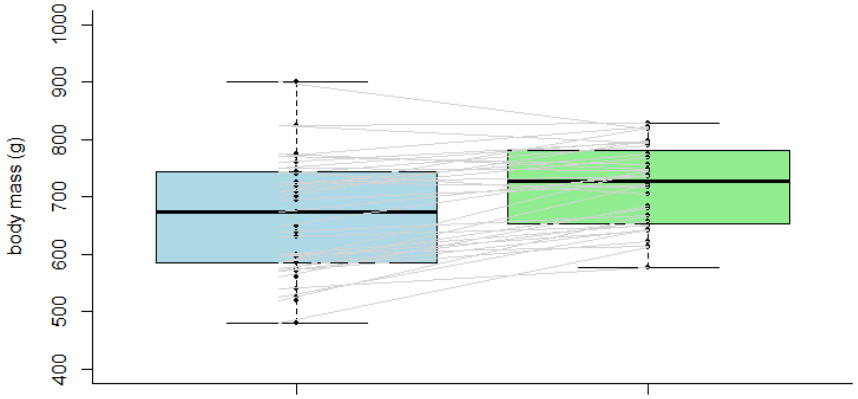
Predicting activity patterns





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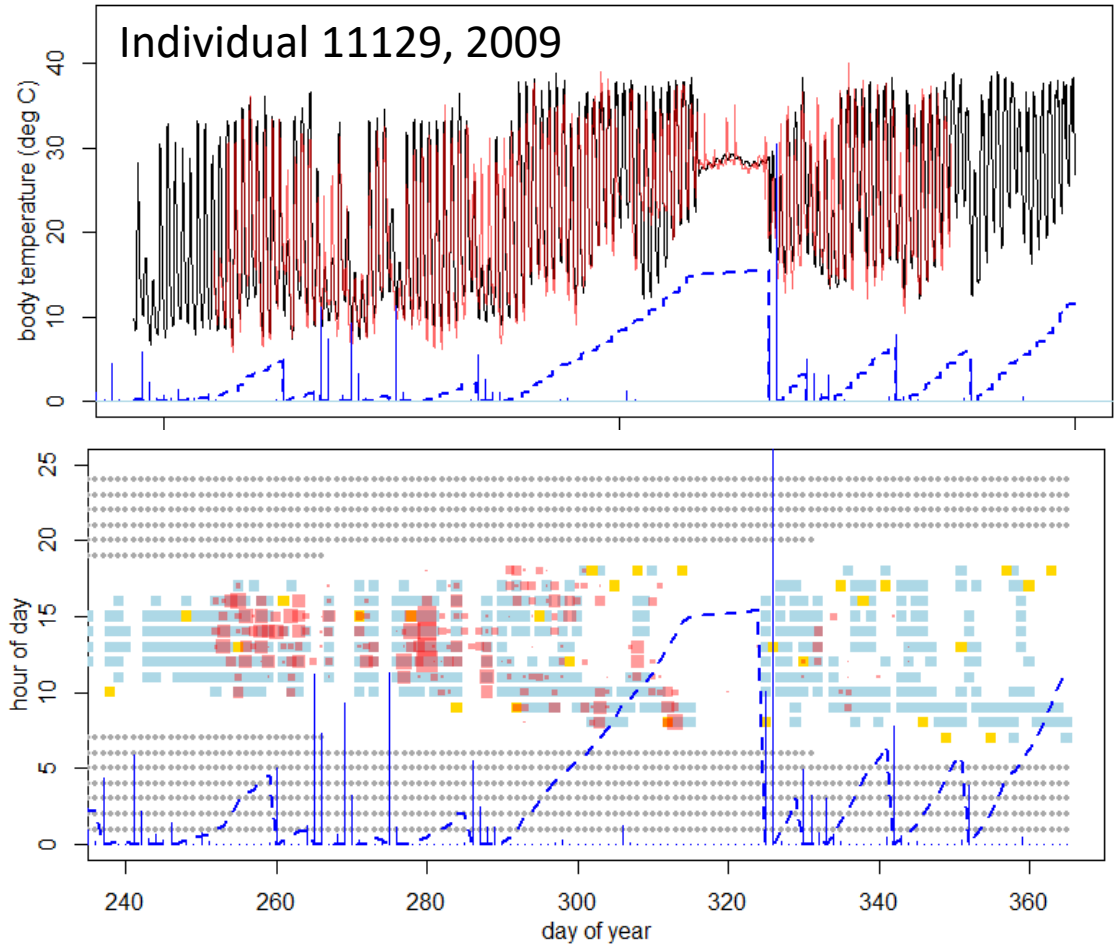
Predicting activity patterns



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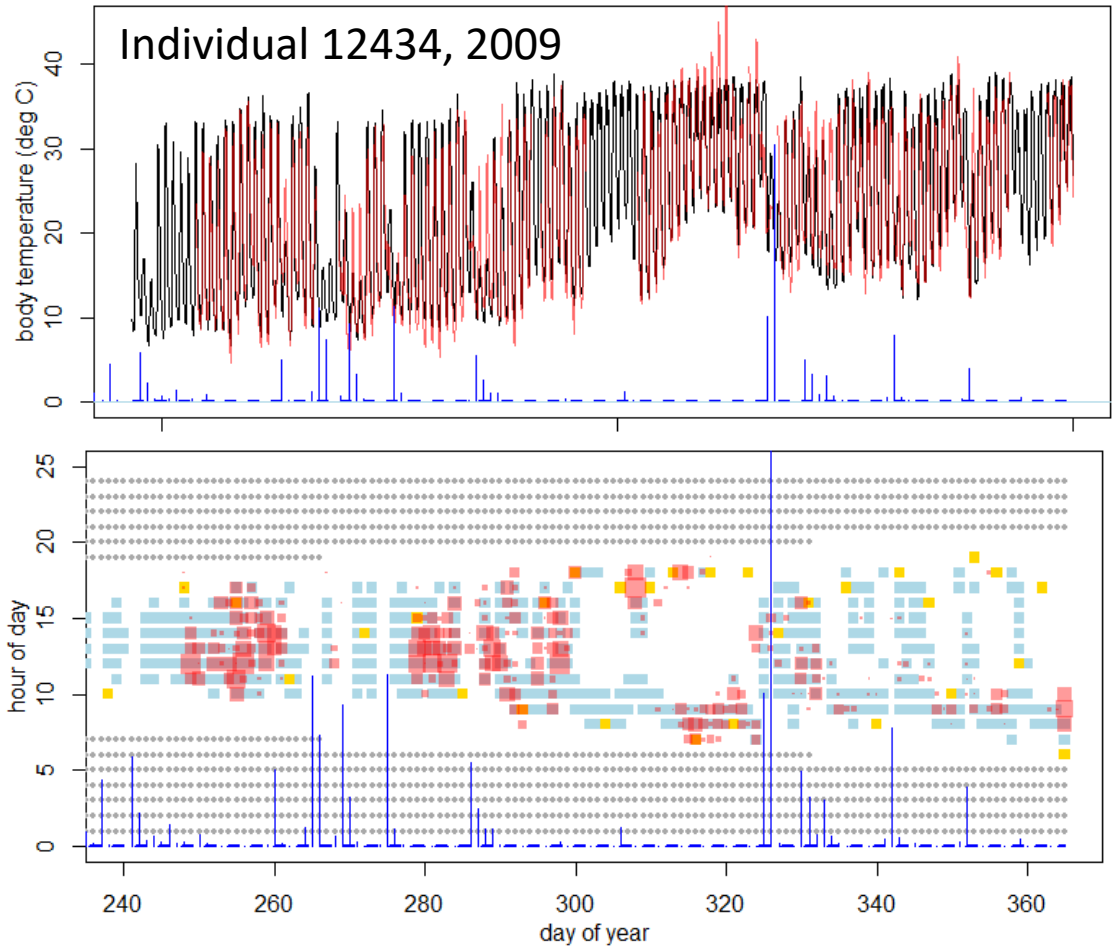
Predicting activity patterns



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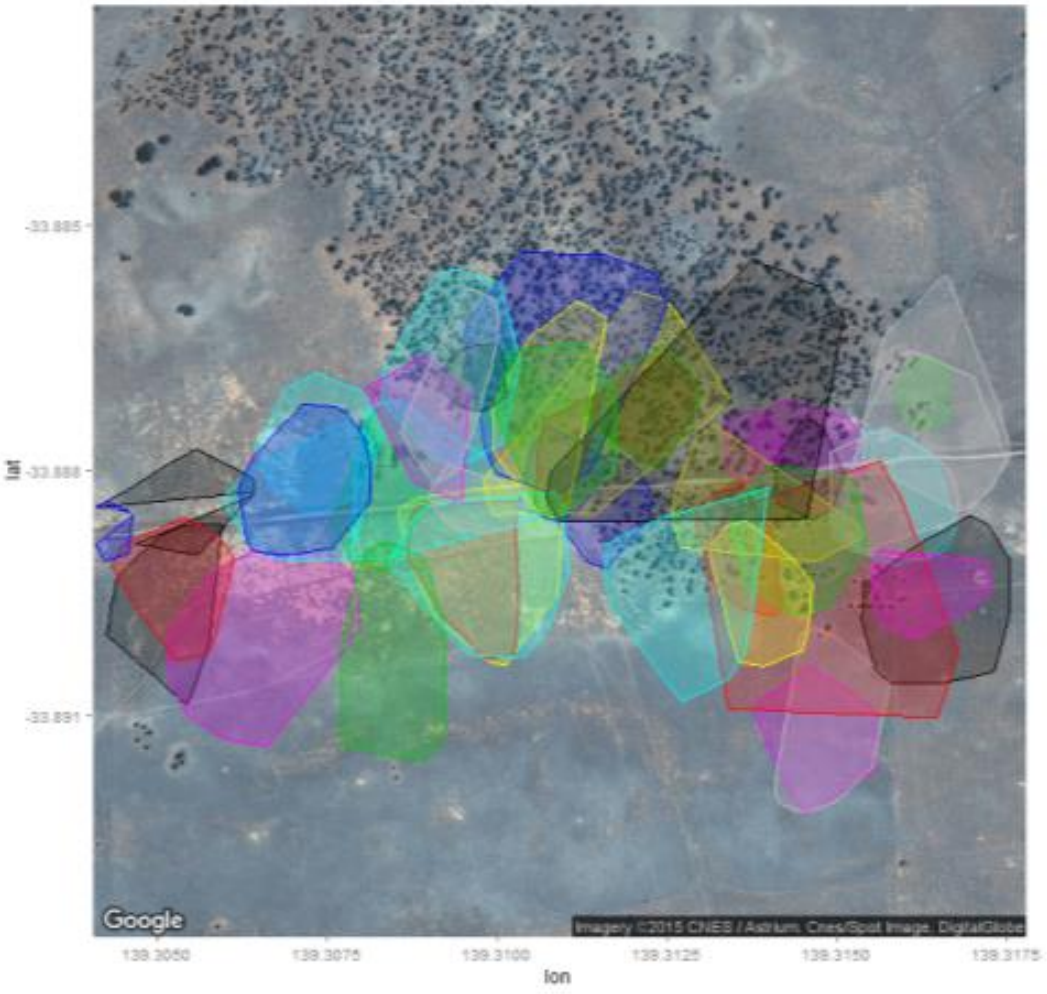
Predicting activity patterns



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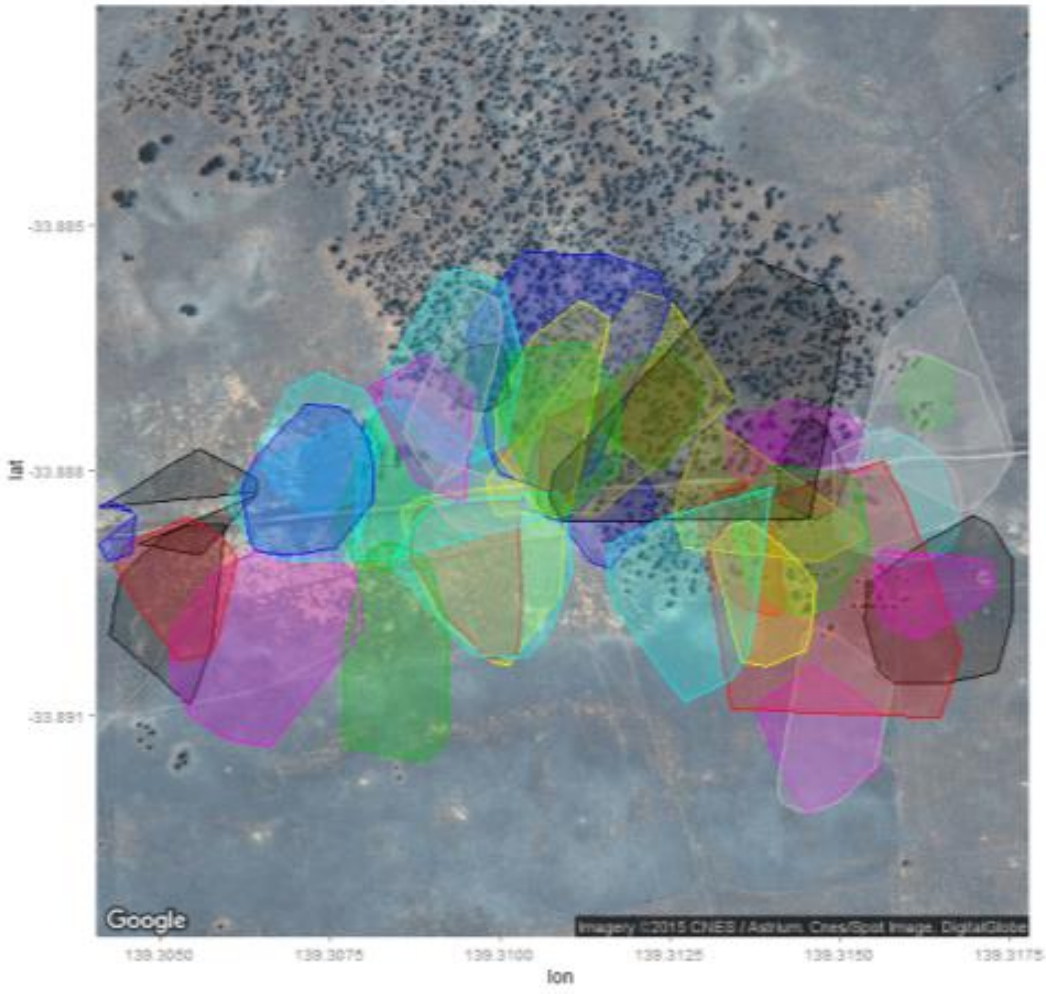
Predicting activity patterns



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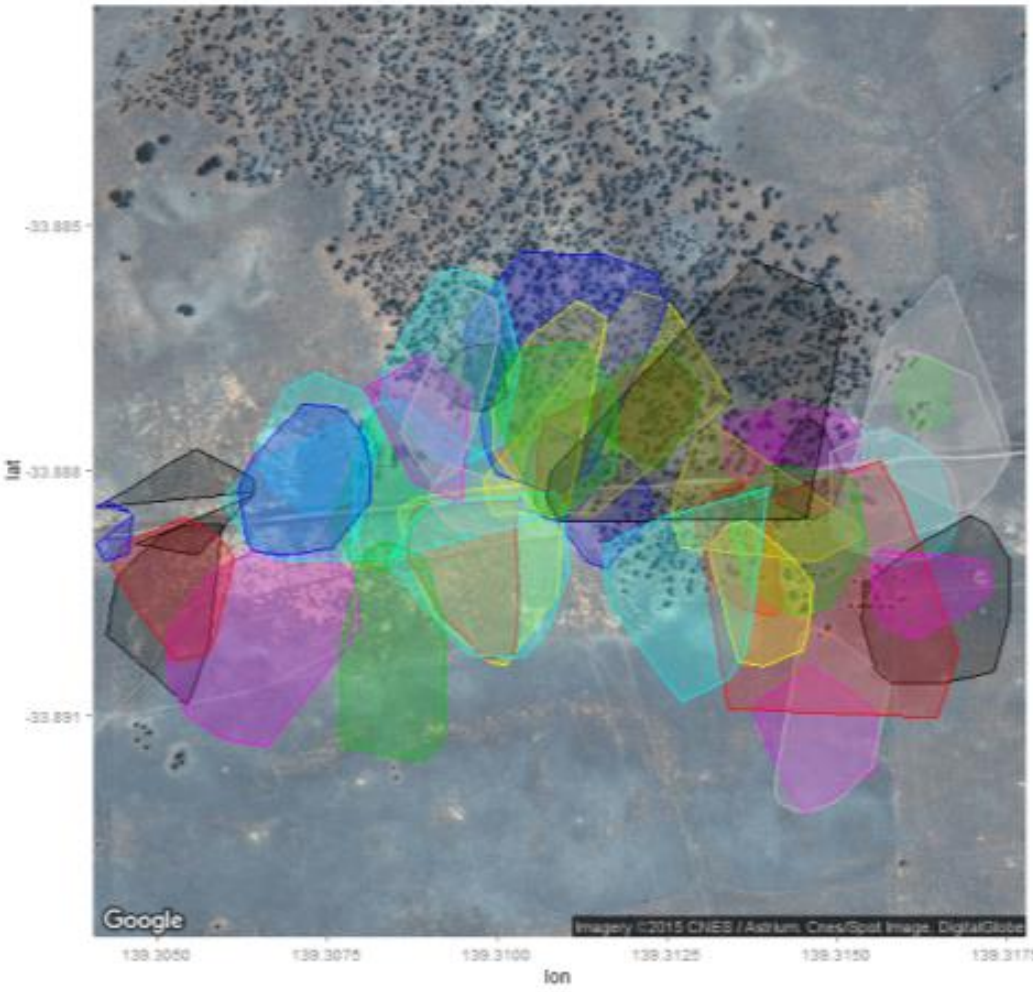
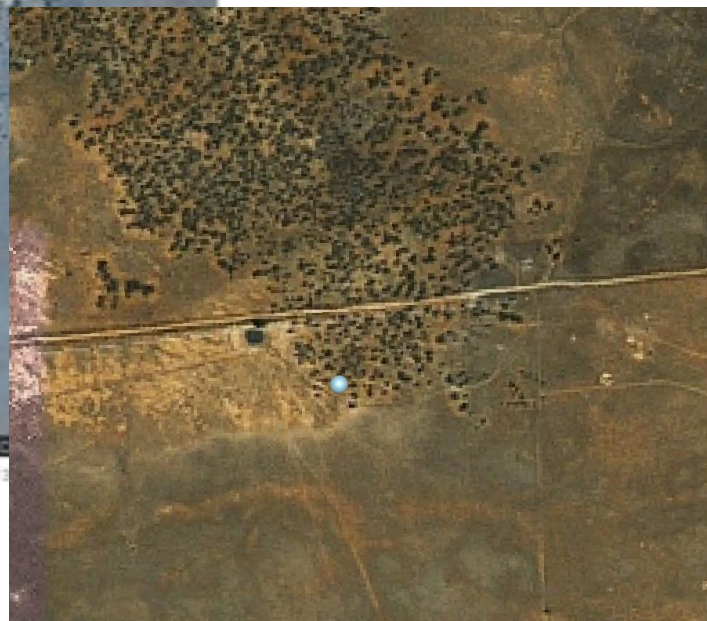
Predicting activity patterns

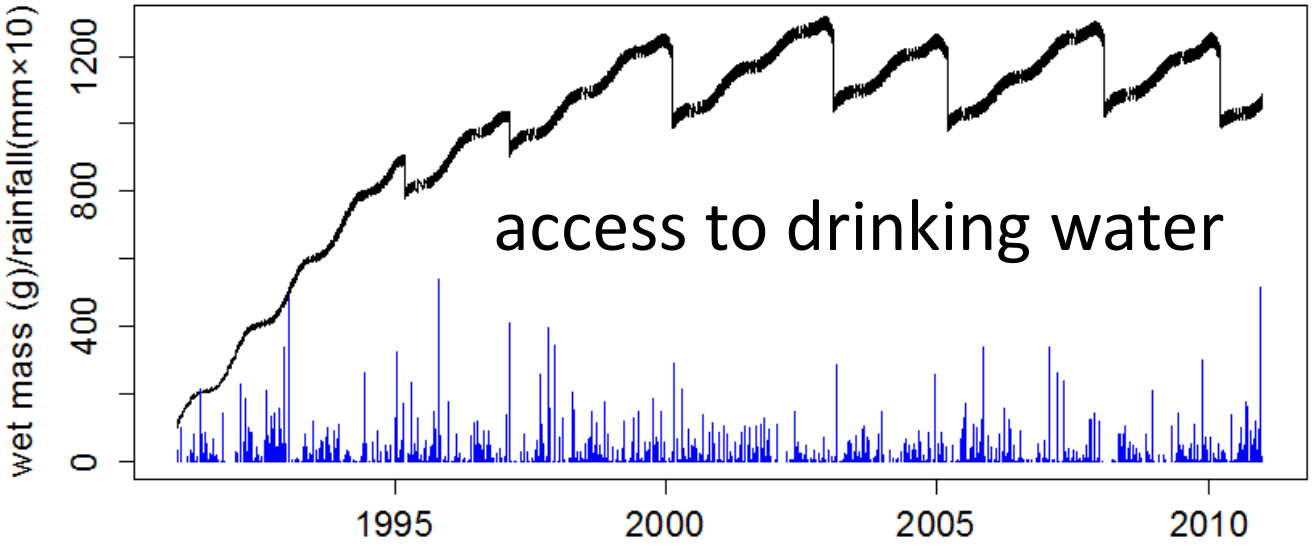


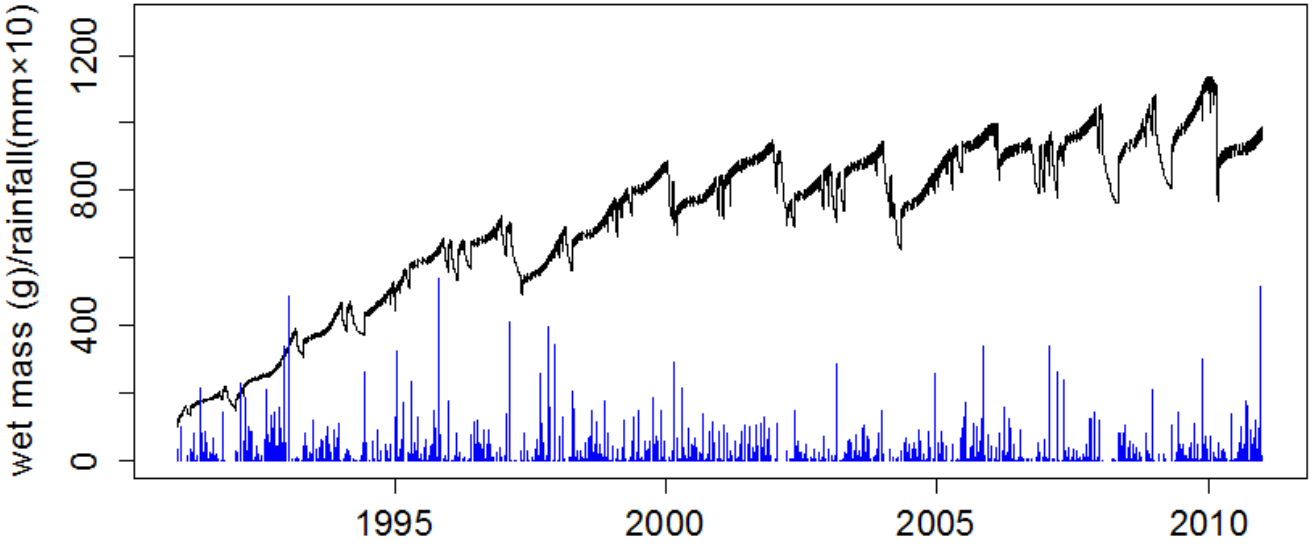


Predicting activity patterns

Water matters!

SLEEPY LIZARD





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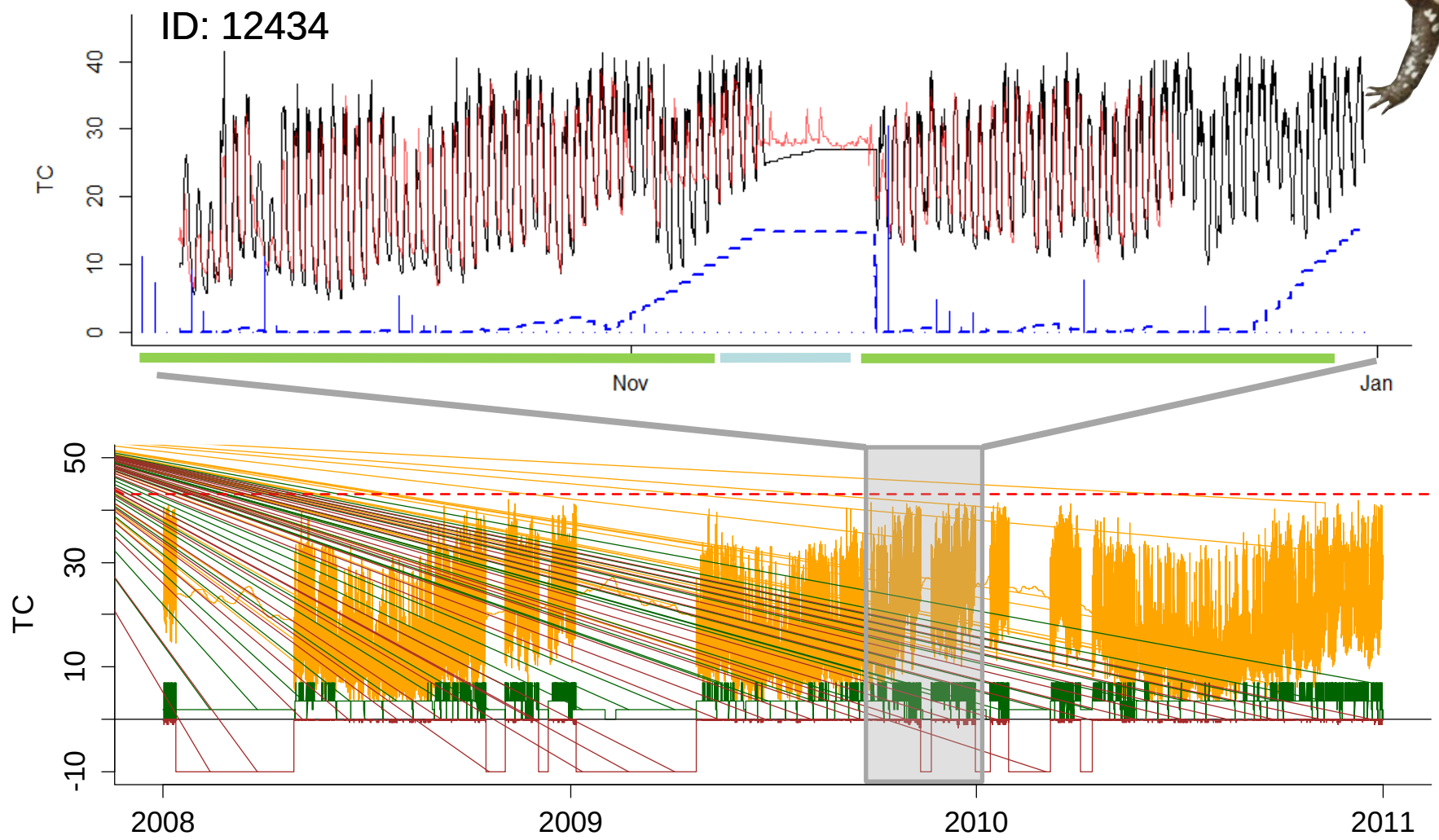
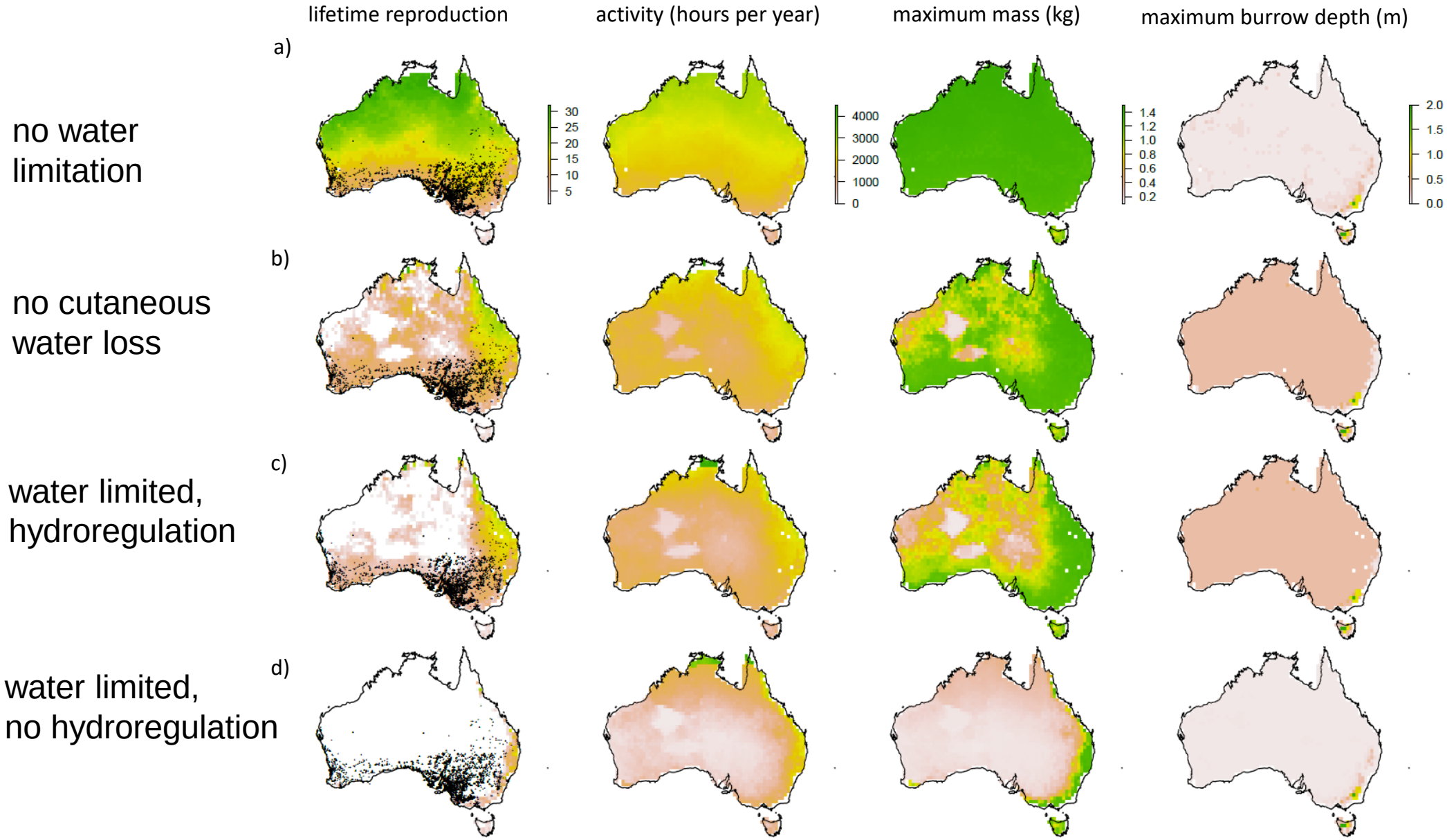
Water matters!



Projecting to the landscape



no water limitation

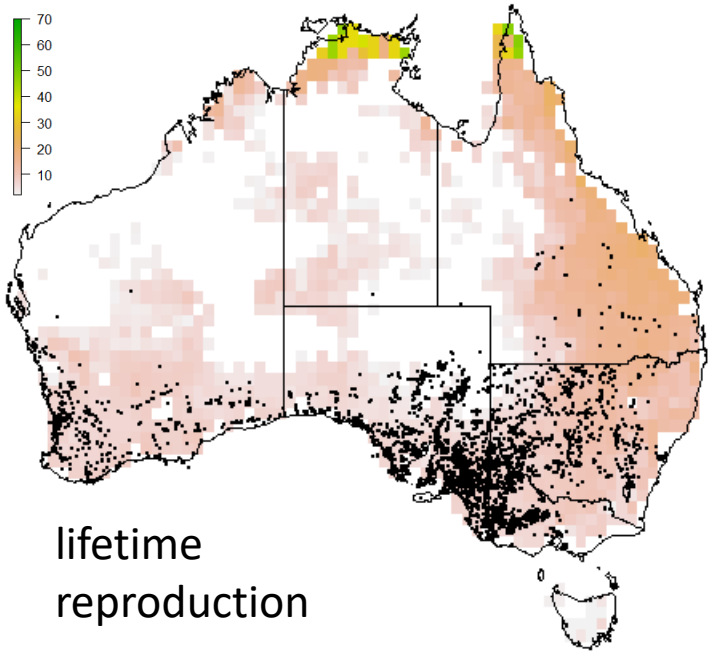
no cutaneous water loss

water limited, hydroregulation

water limited, no hydroregulation

Projecting to the landscape

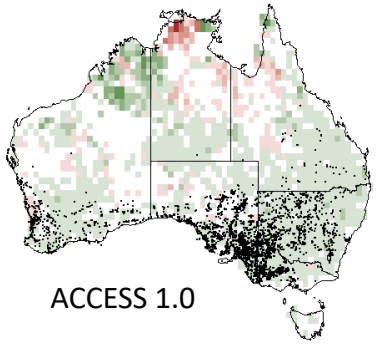
1990-2009



lifetime
reproduction

Projecting to the future

2060-2080



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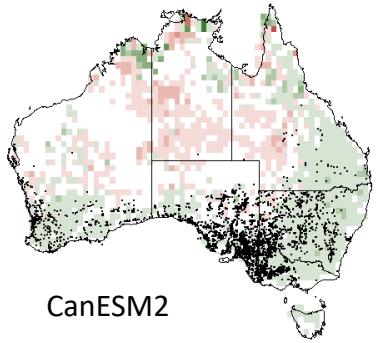
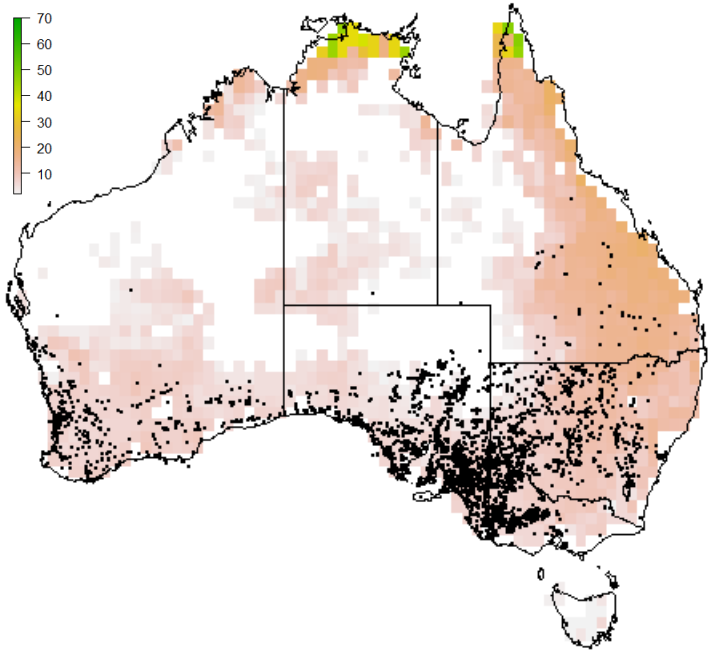
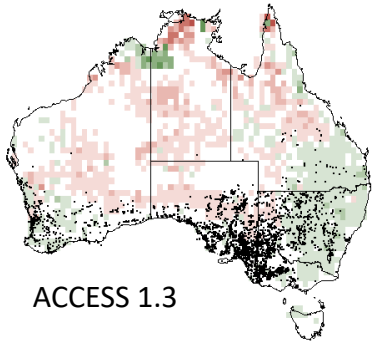


CanESM2





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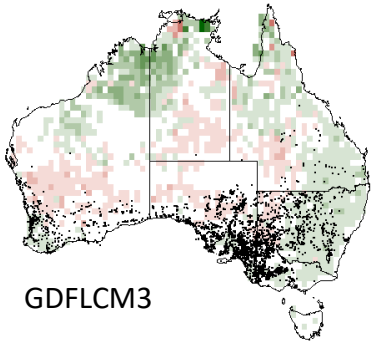
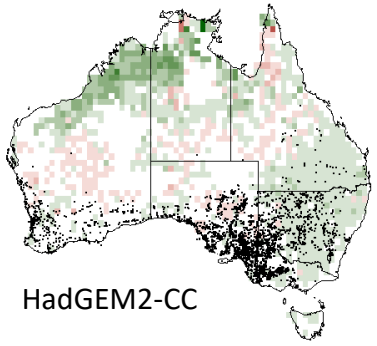


GDFLCM3



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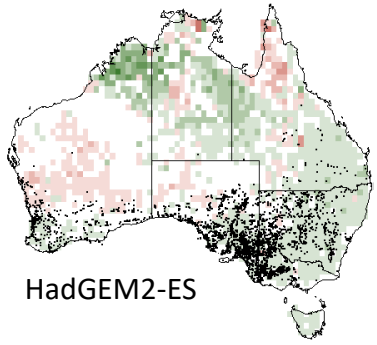
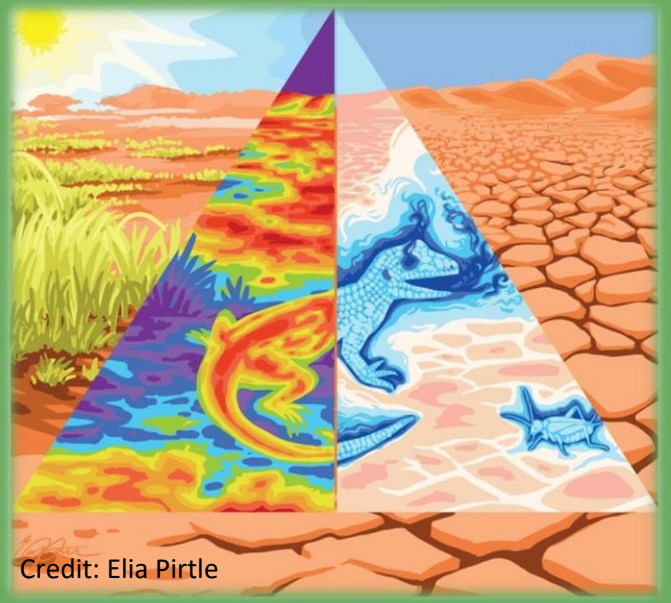


HadGEM2-ES



Credit: Elia Pirtle

4.

Butterfly life cycle model

Capturing a complex life cycle

Multiple limiting factors through space

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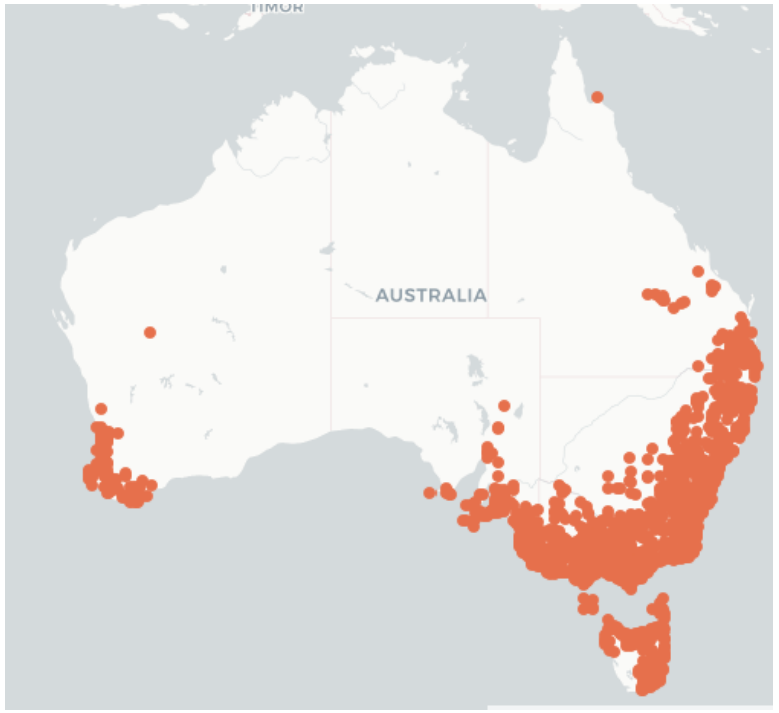
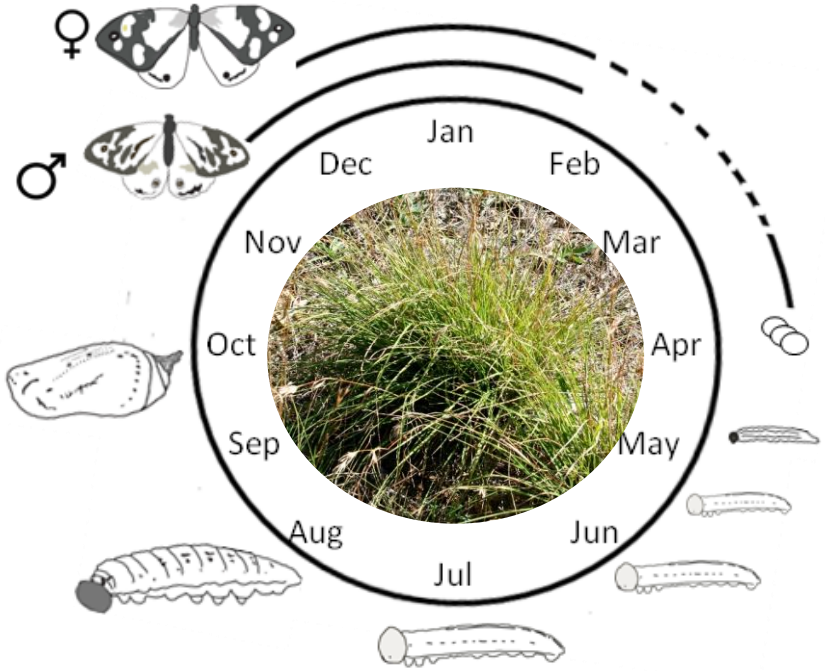
Common Brown Butterfly *Heteronympha merope*

Photo: Trevor Rowe/Roger Gund





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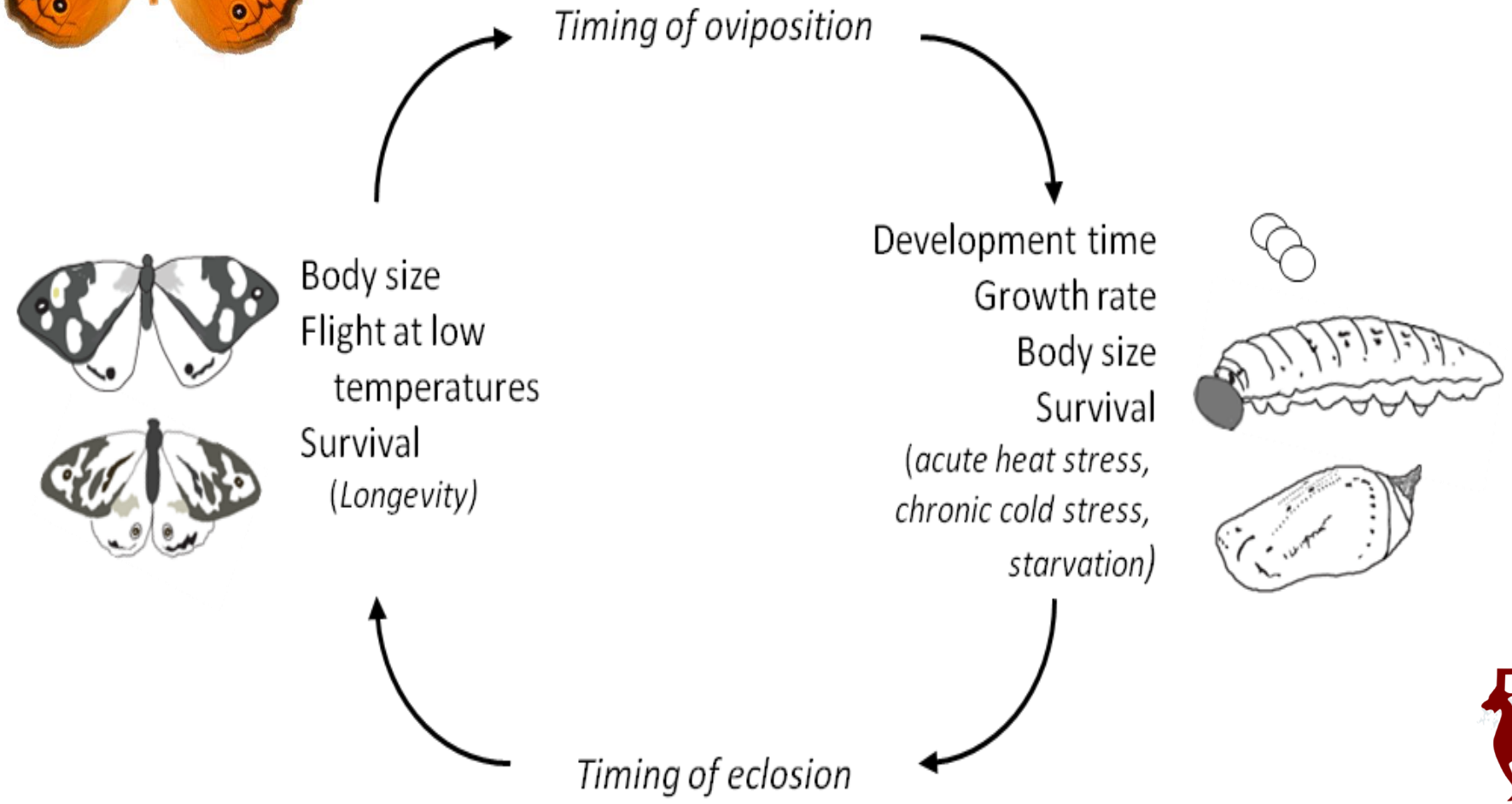
Common Brown Butterfly *Heteronympha merope*



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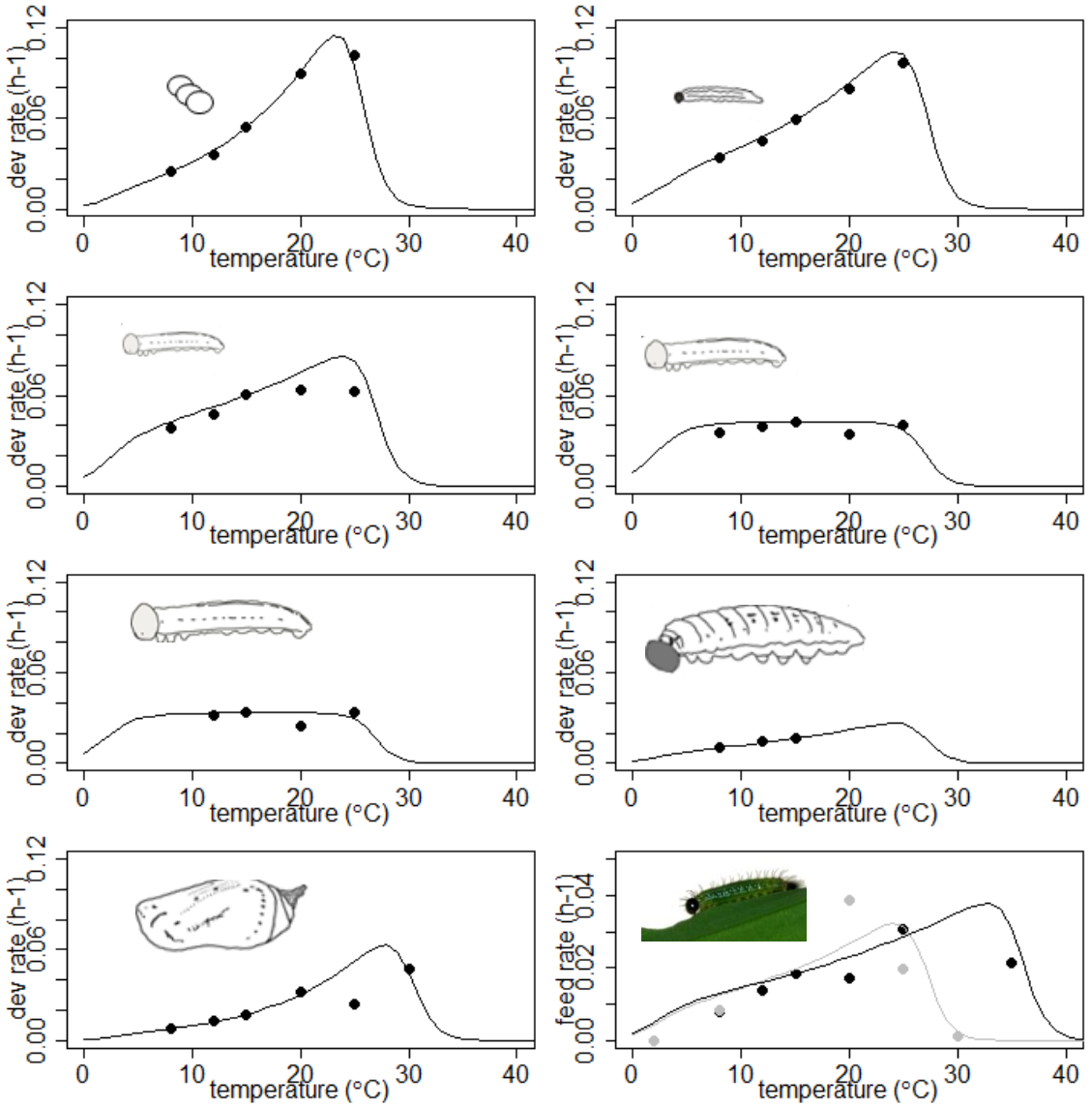
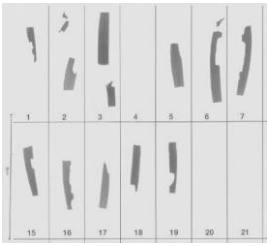
Stage-dependent thermal responses

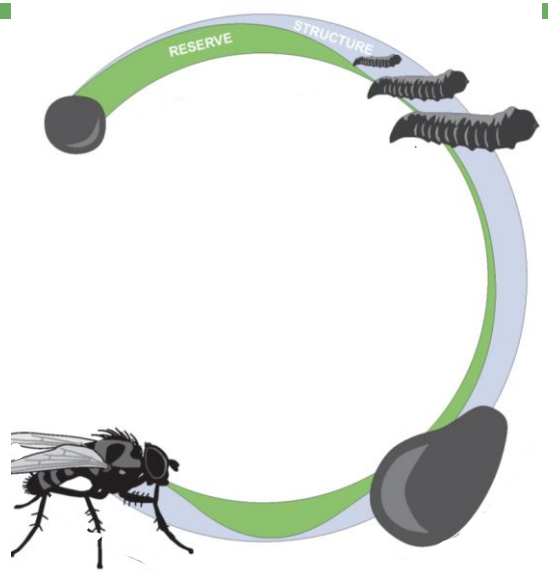
Dr Natalie Briscoe

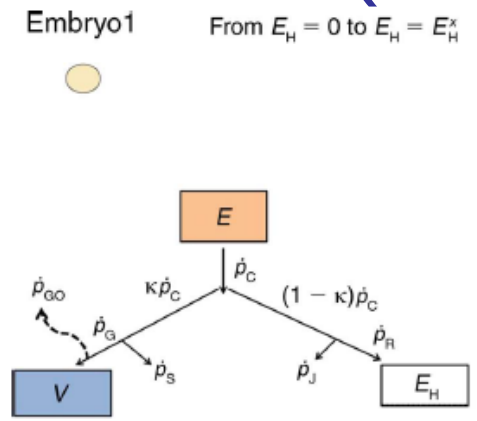


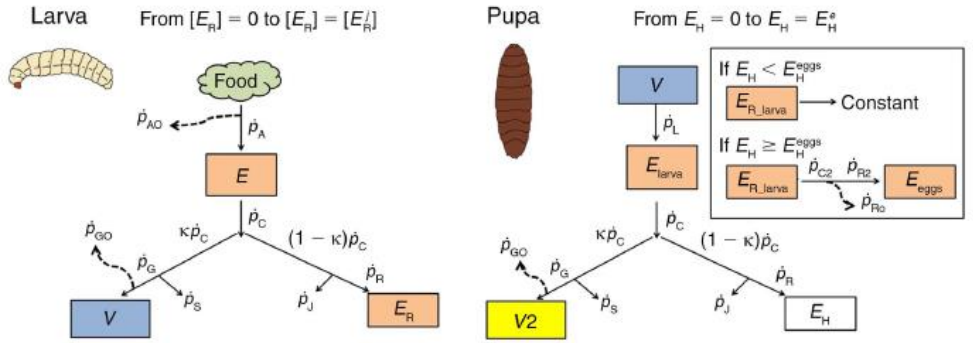


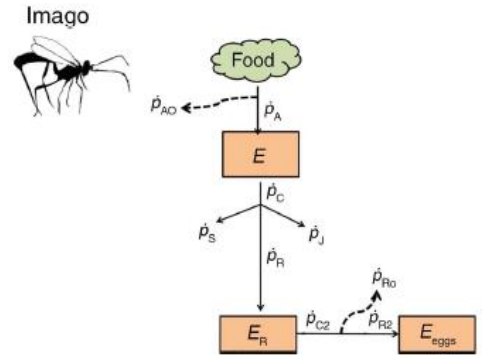
Briscoe et al. 2012. Stage-dependent physiological responses in a butterfly cause non-additive effects on phenology. Oikos 121:1464–1472.

DEB holometabolous (hex) model









Llandres et al. (2015). A dynamic energy budget for the whole life-cycle of holometabolous insects. *Ecological Monographs* **85**, 353–371.

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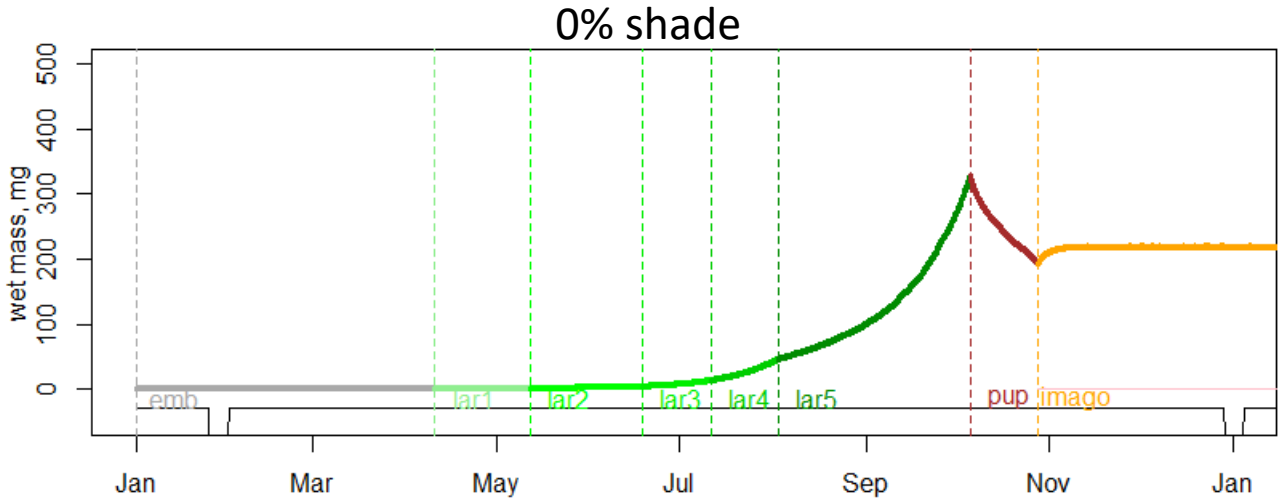
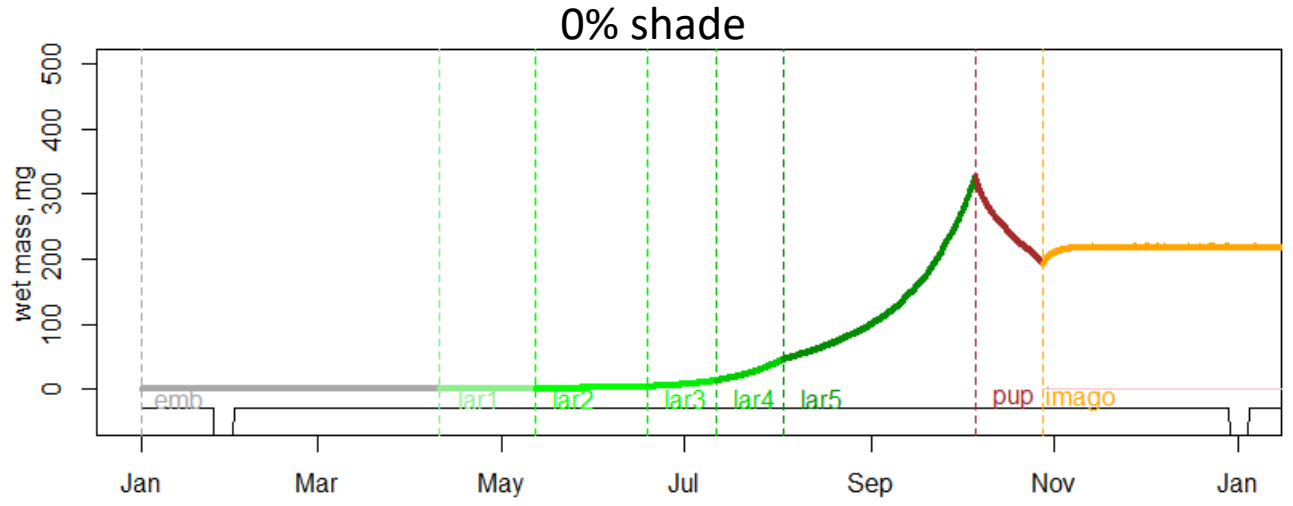
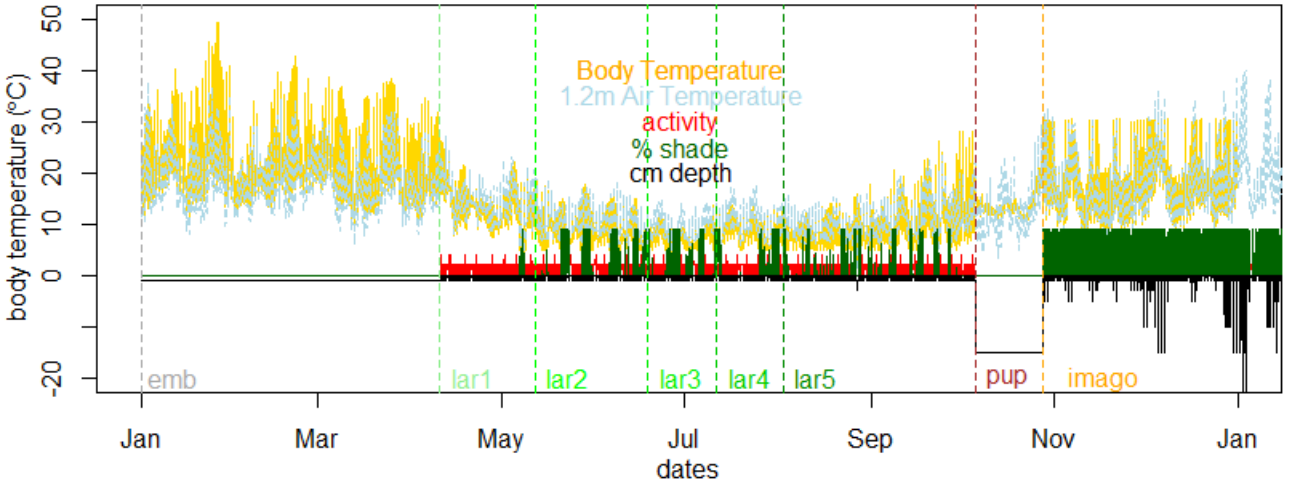
Simulating lifecycle trajectories



Melbourne

Simulating lifecycle trajectories





Melbourne

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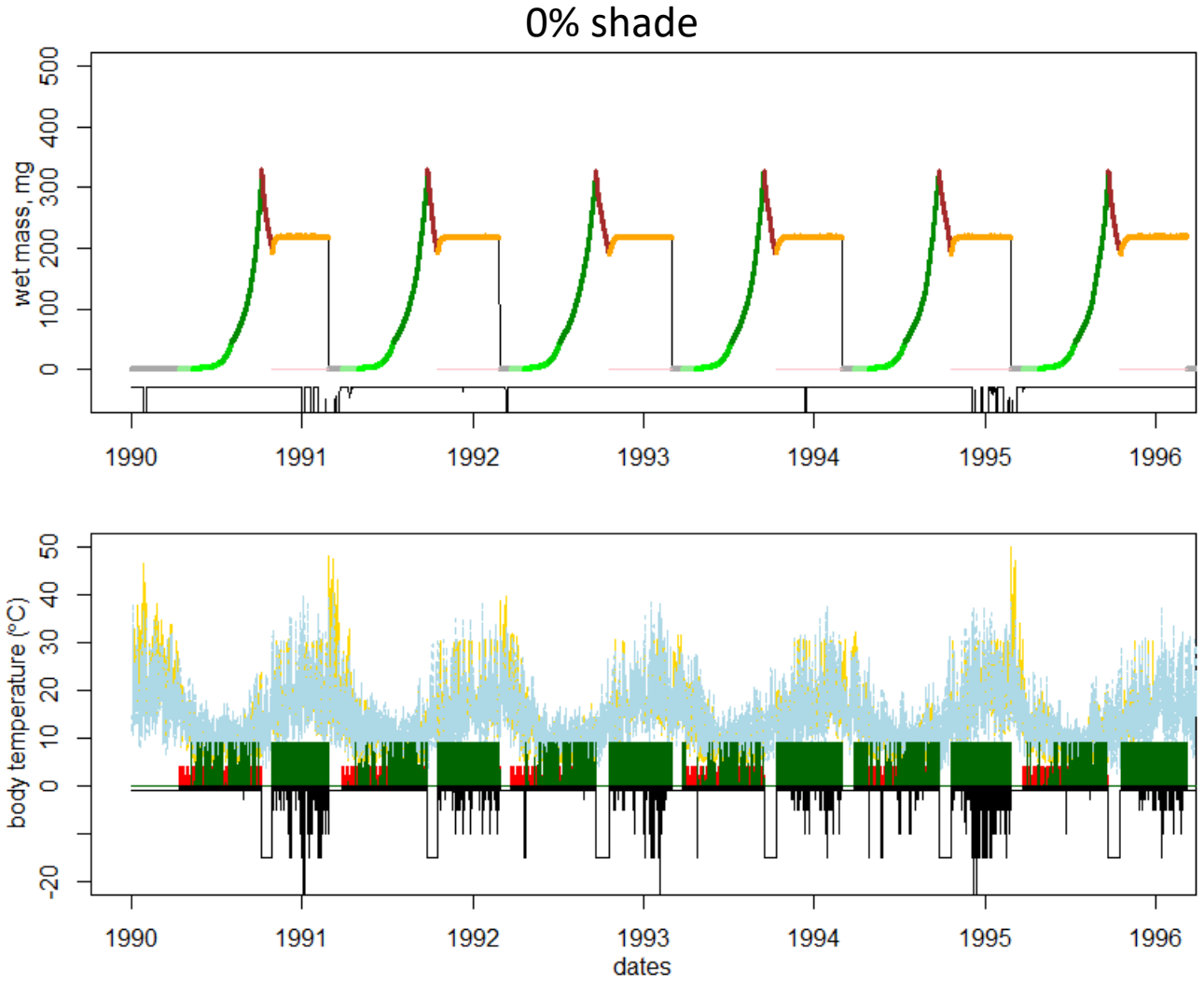
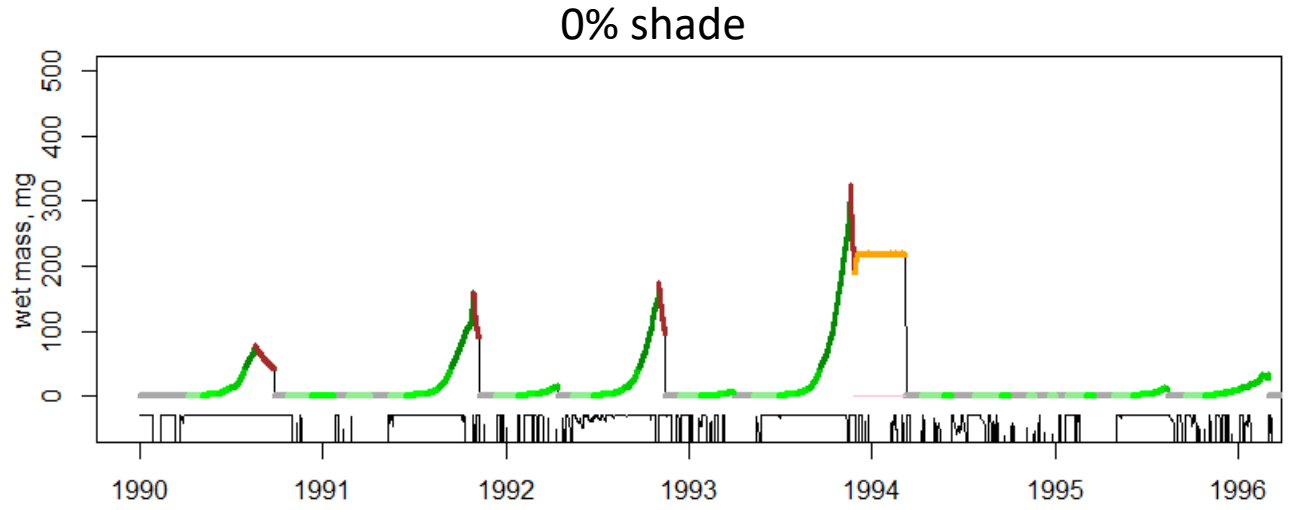
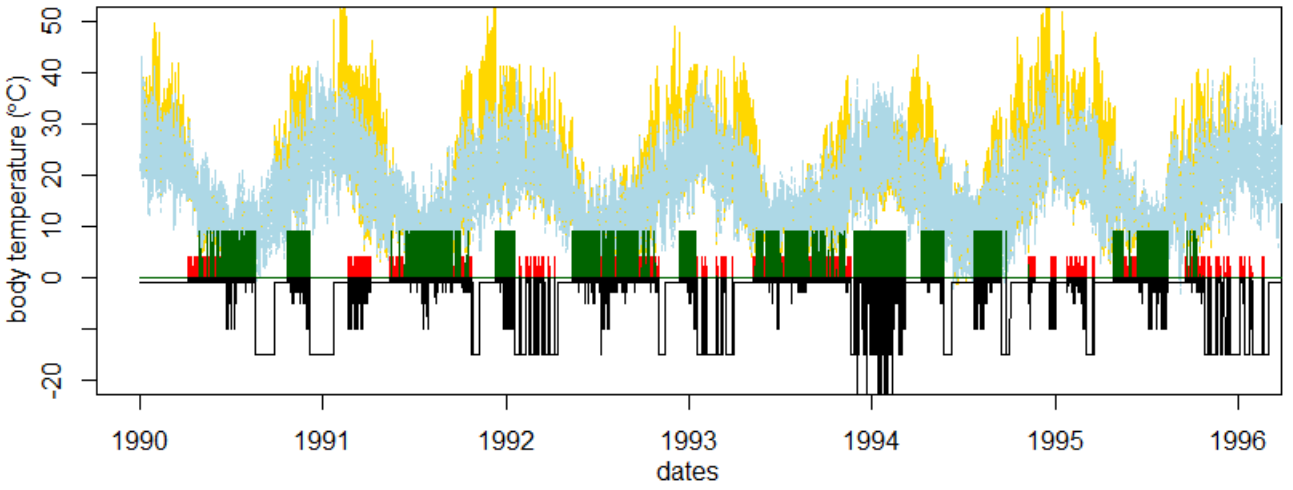
Simulating lifecycle trajectories



Melbourne

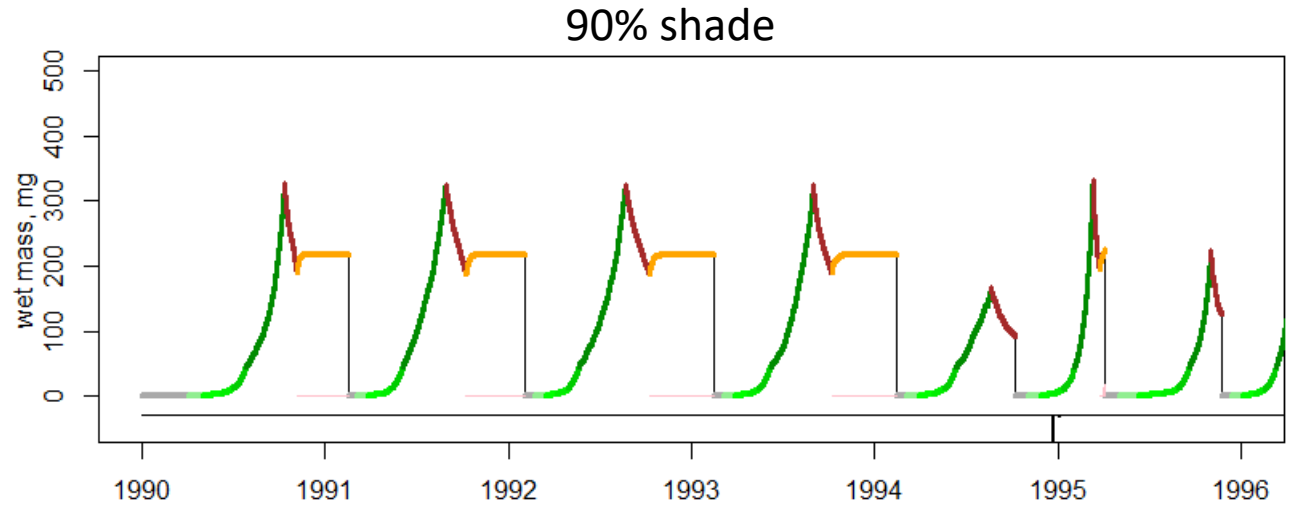
Simulating lifecycle trajectories

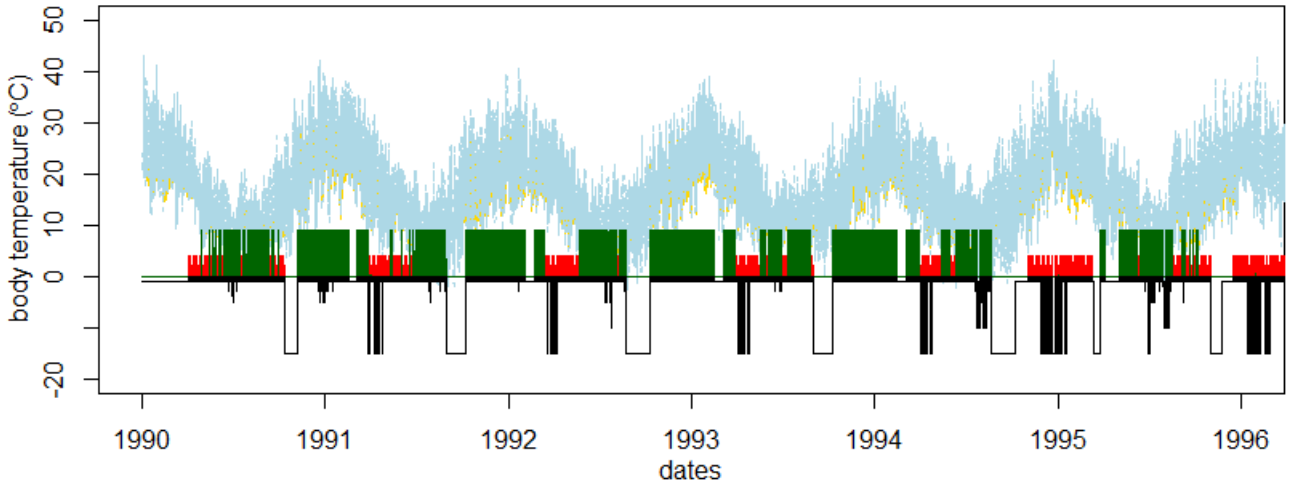




Dubbo

Simulating lifecycle trajectories





Dubbo

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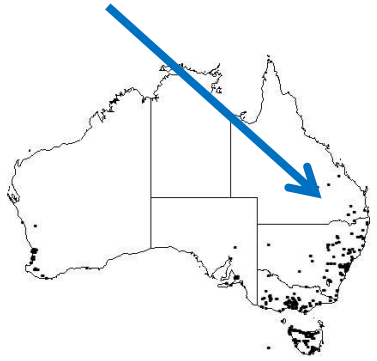
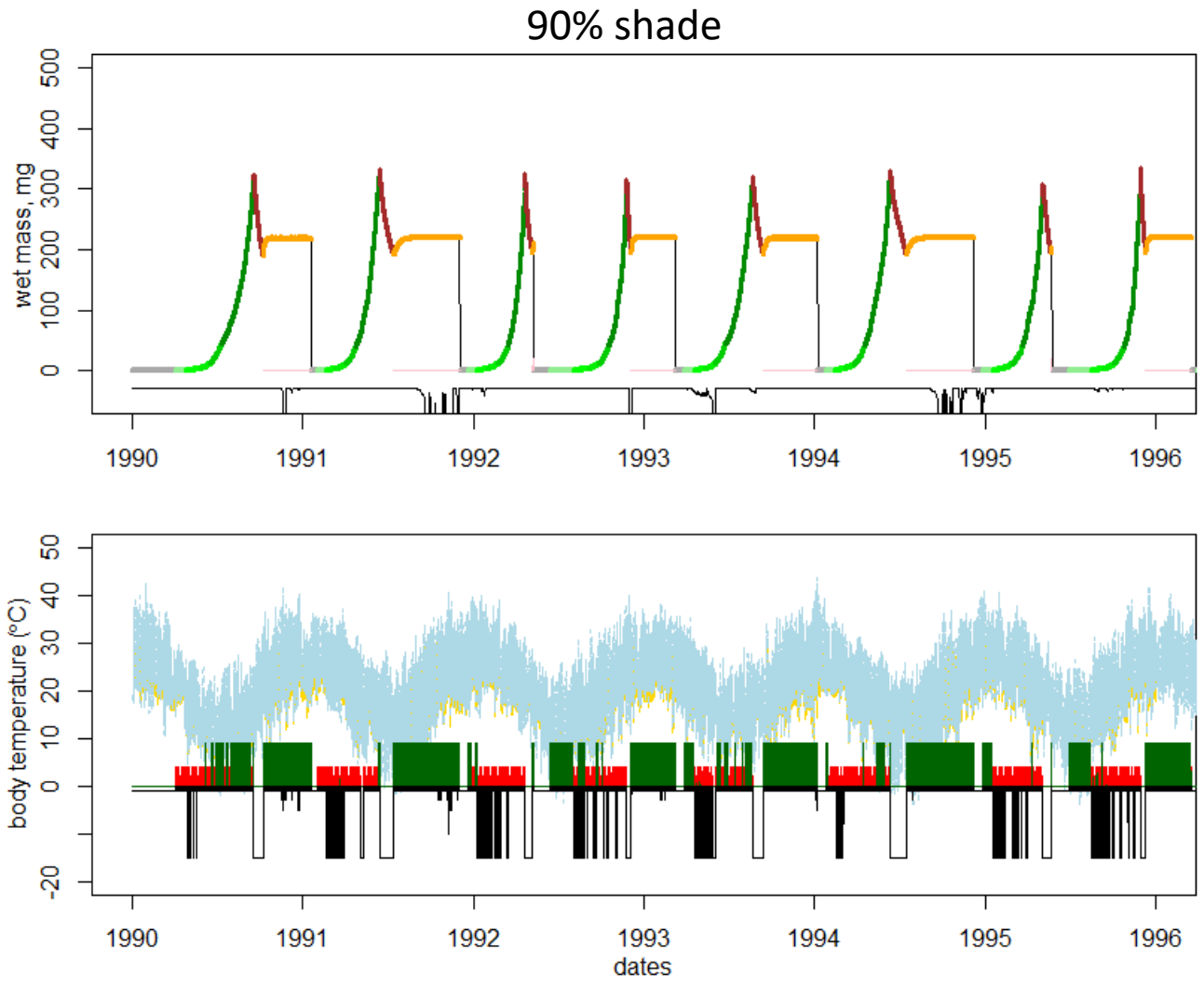
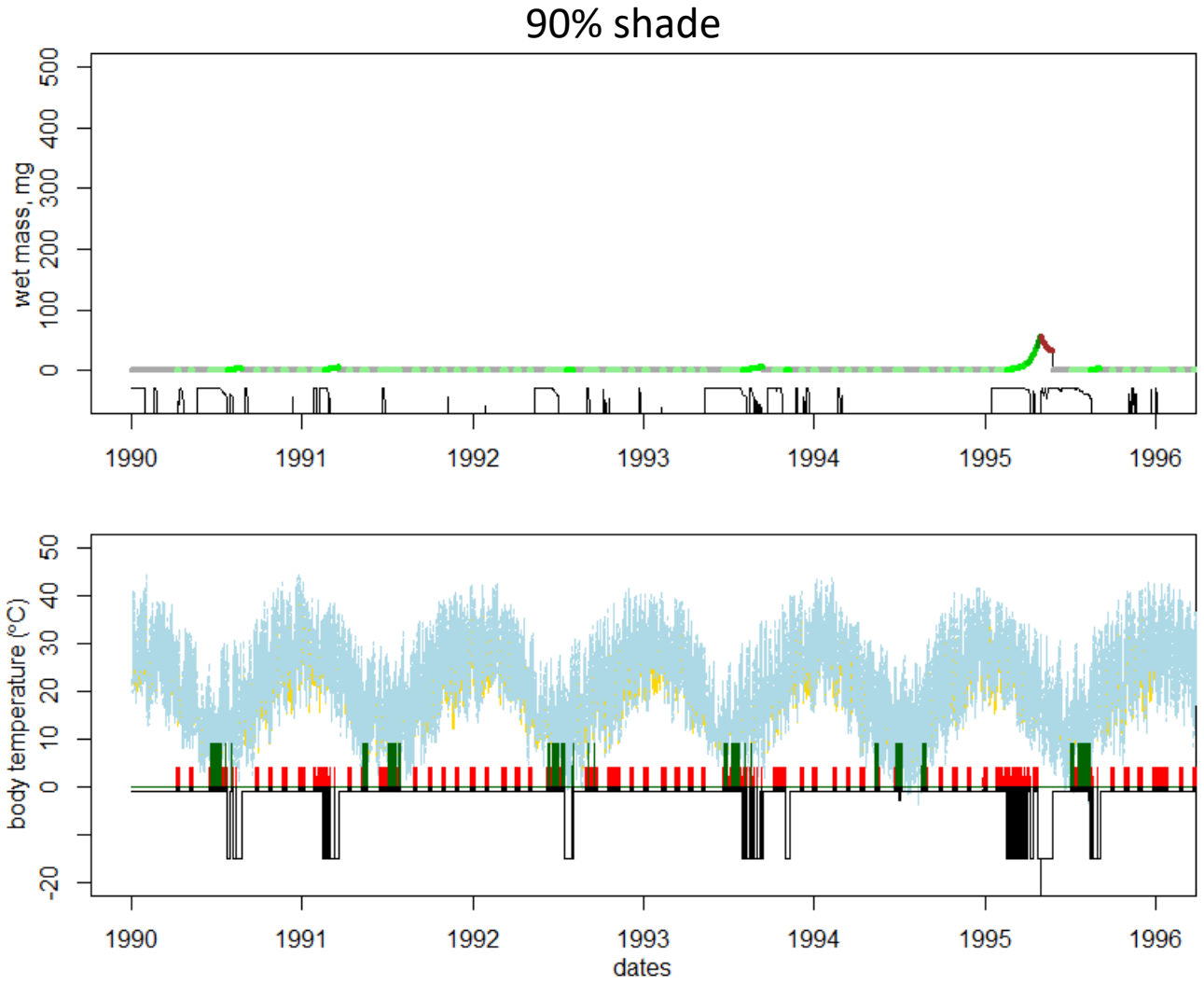
Simulating lifecycle trajectories

Carnarvon Gorge



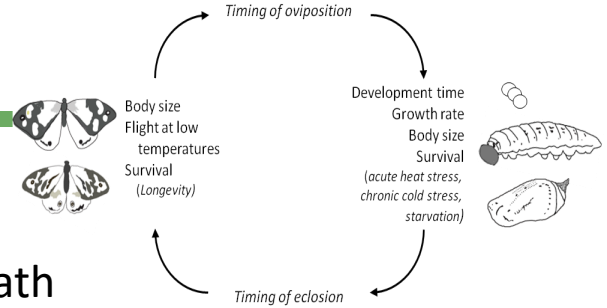


Simulating lifecycle trajectories

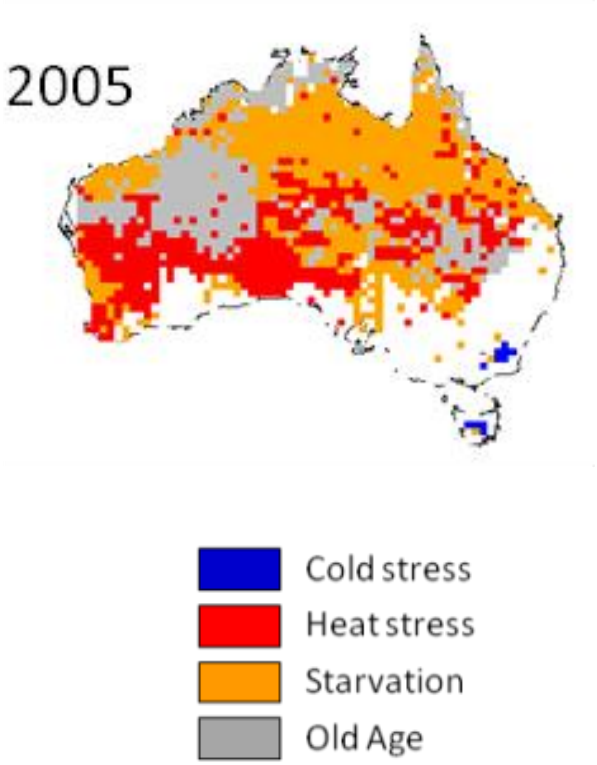


Alice Springs

Species distribution model post-mortem



Cause of Death



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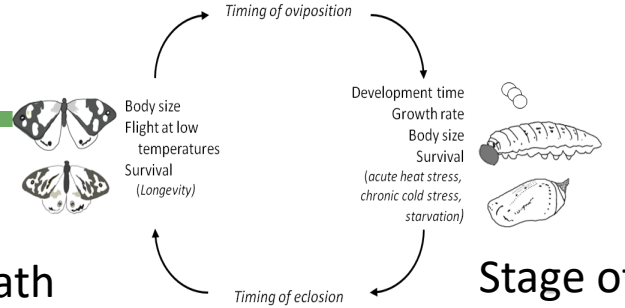
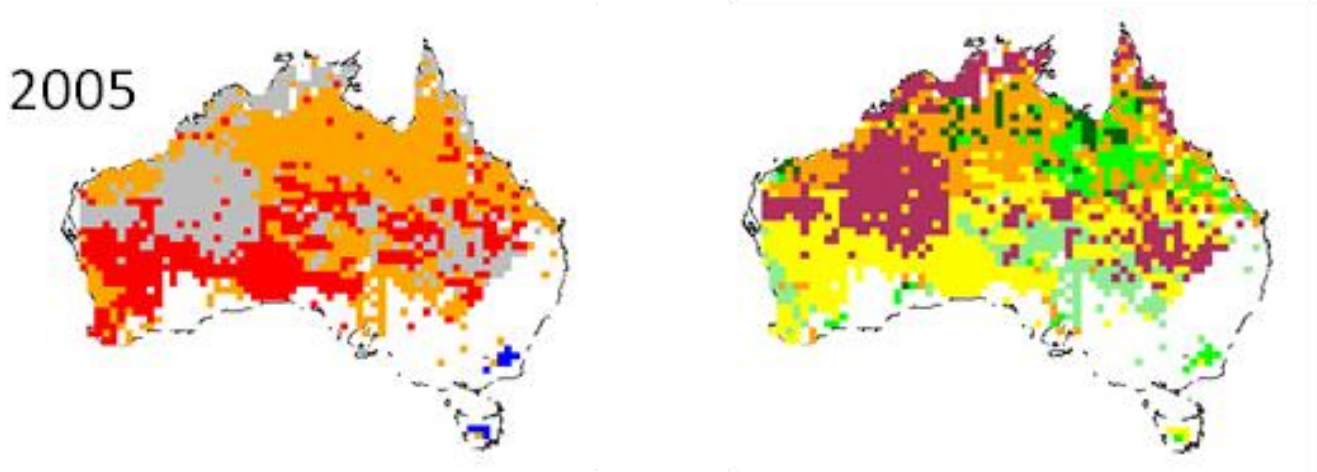
Species distribution model post-mortem



Cause of Death

Stage of Death



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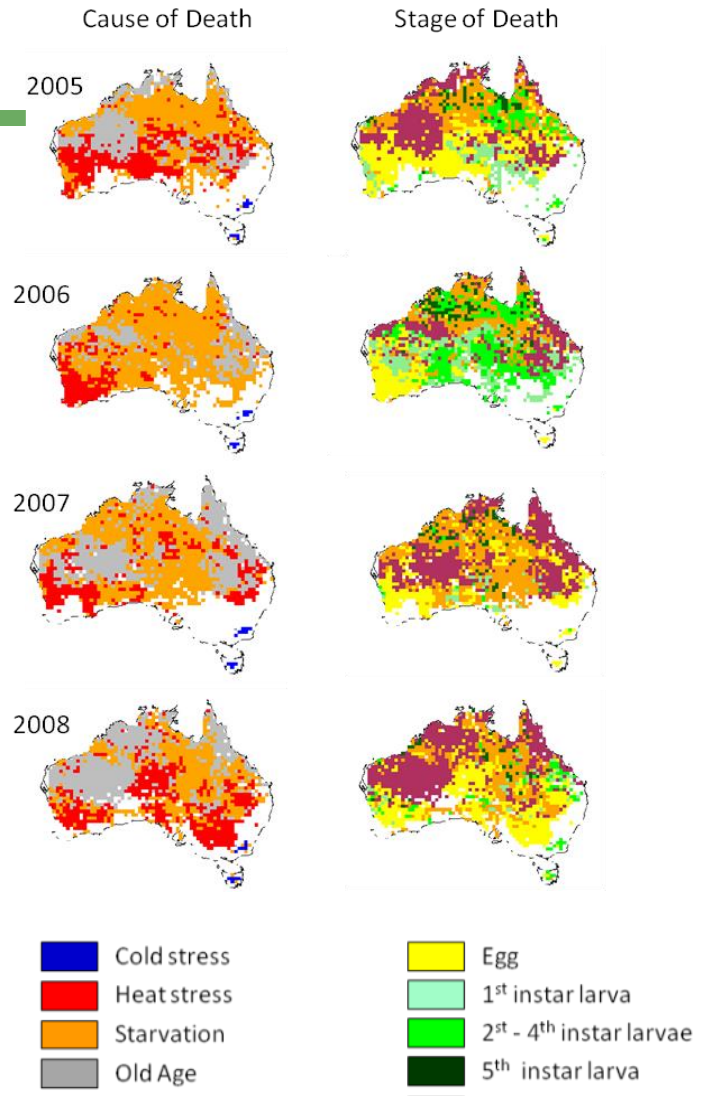
Species distribution model post-mortem



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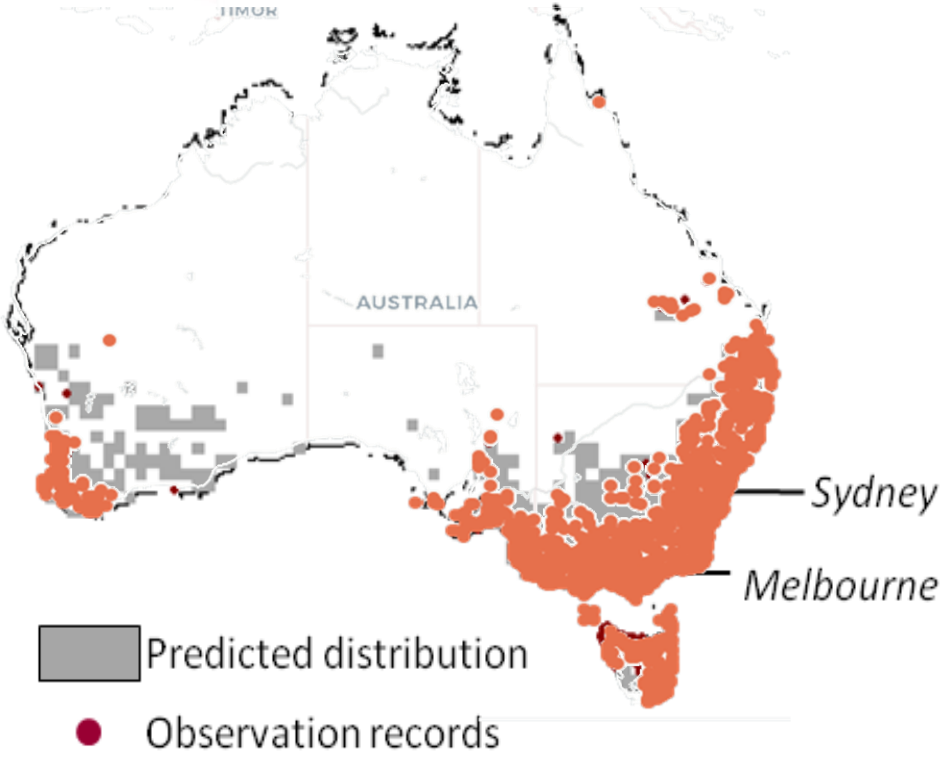
Predicting the distribution



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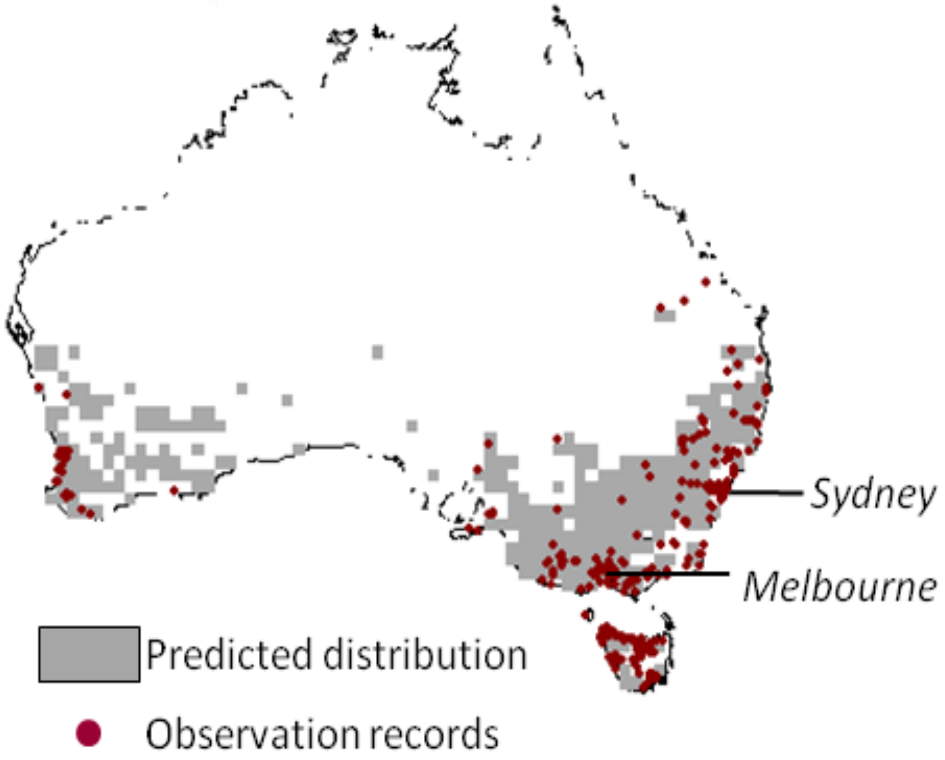
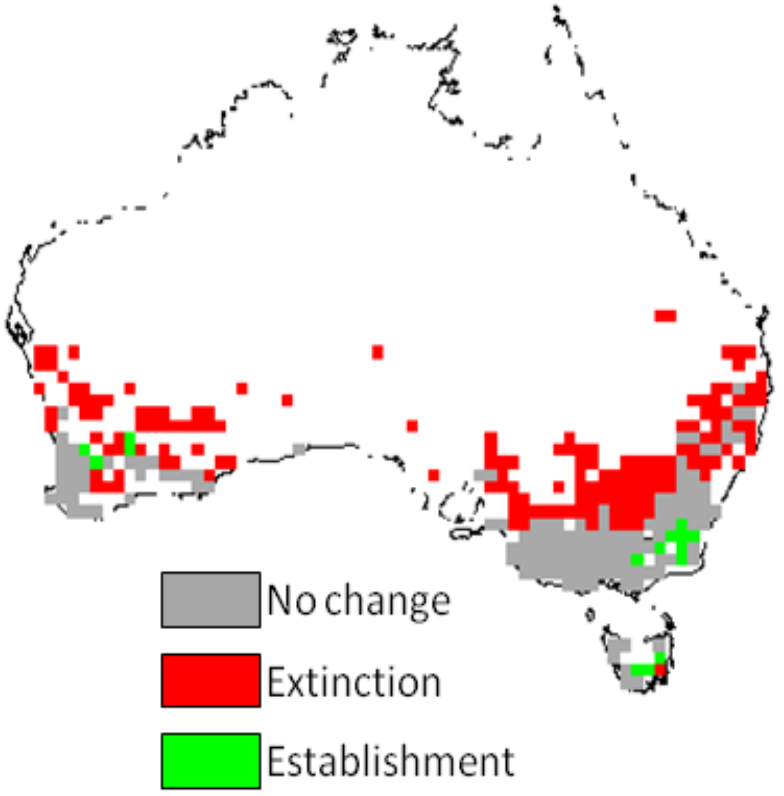
Predicting the distribution



+ 3°C



Thermodynamic basis to the niche

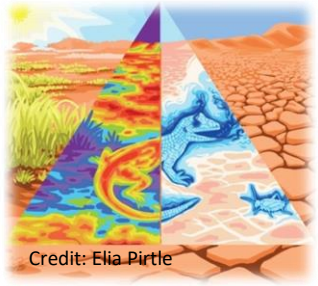
p = heat flux
J = mass flux
X = food
H = water
I = ingested
P = product (faeces)
U = urinated
G = growth
R = reproduction
S = stored
O_2 = oxygen
CO_2 = carbon dioxide
N = nitrogenous waste
MET = 'metabolism'
EVAP = evaporation
SOLAR = solar radiation
IR = infrared radiation
CONV = convection
COND = conduction

$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{J, p\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P}$$

$$= p_{IR,out} + J_{CO2,MET} + J_{N,MET} + p_{CONV} + J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \{J, p\}_{EVAP} + p_{COND}$$

heat

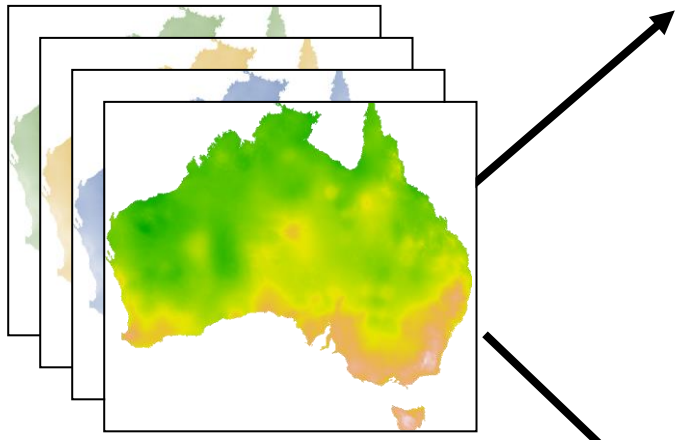
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$



Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

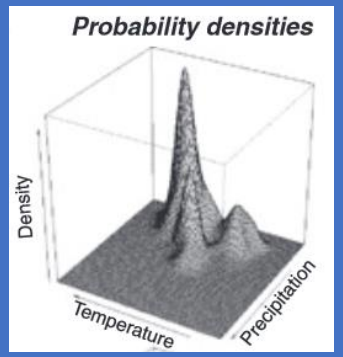
DEB 2025
School: 26 May - 3 Jun 2025
University of Crete, Heraklion, Greece

Ecological Niche Modelling

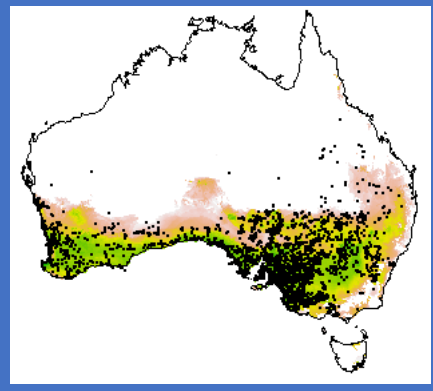


Correlative Model (process implicit)

Maxent model



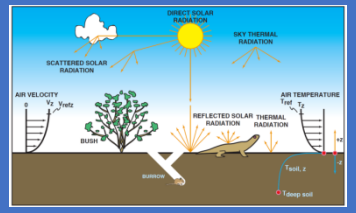
probability of occurrence

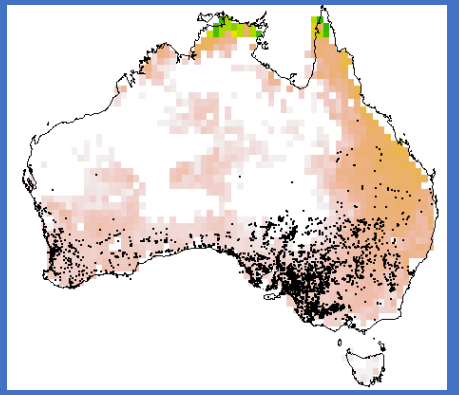


Mechanistic Model (process explicit)

potential reproduction

Thermodynamic Niche Model





Thank you for your attention

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