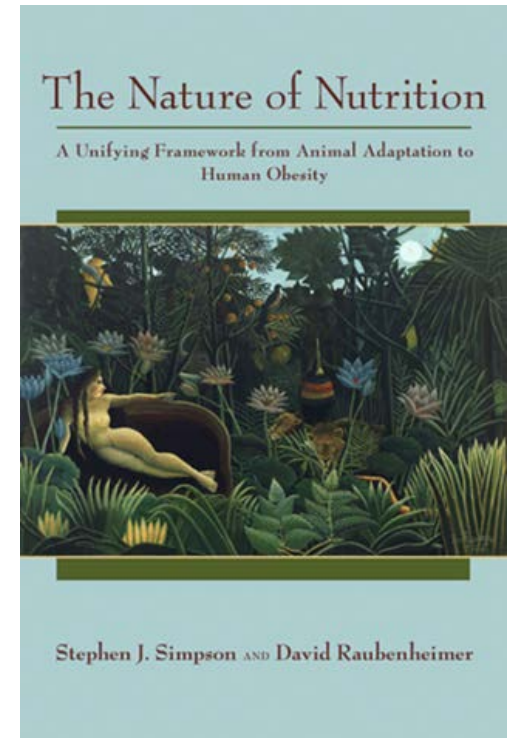
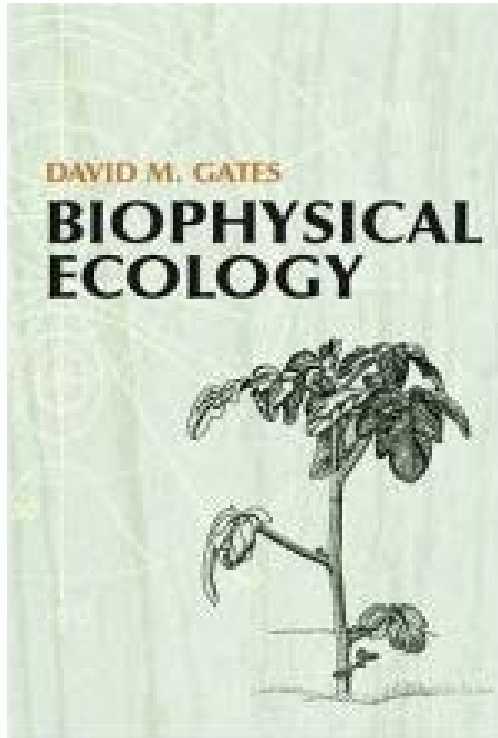
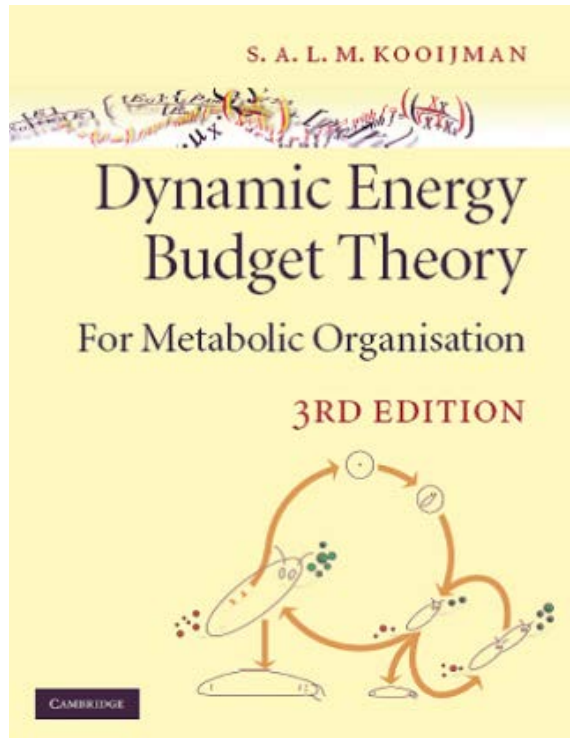



Mechanistic Niche Models



Michael Kearney mrke@unimelb.edu.au
School of BioSciences, The University of Melbourne

Mechanistic Niche Models

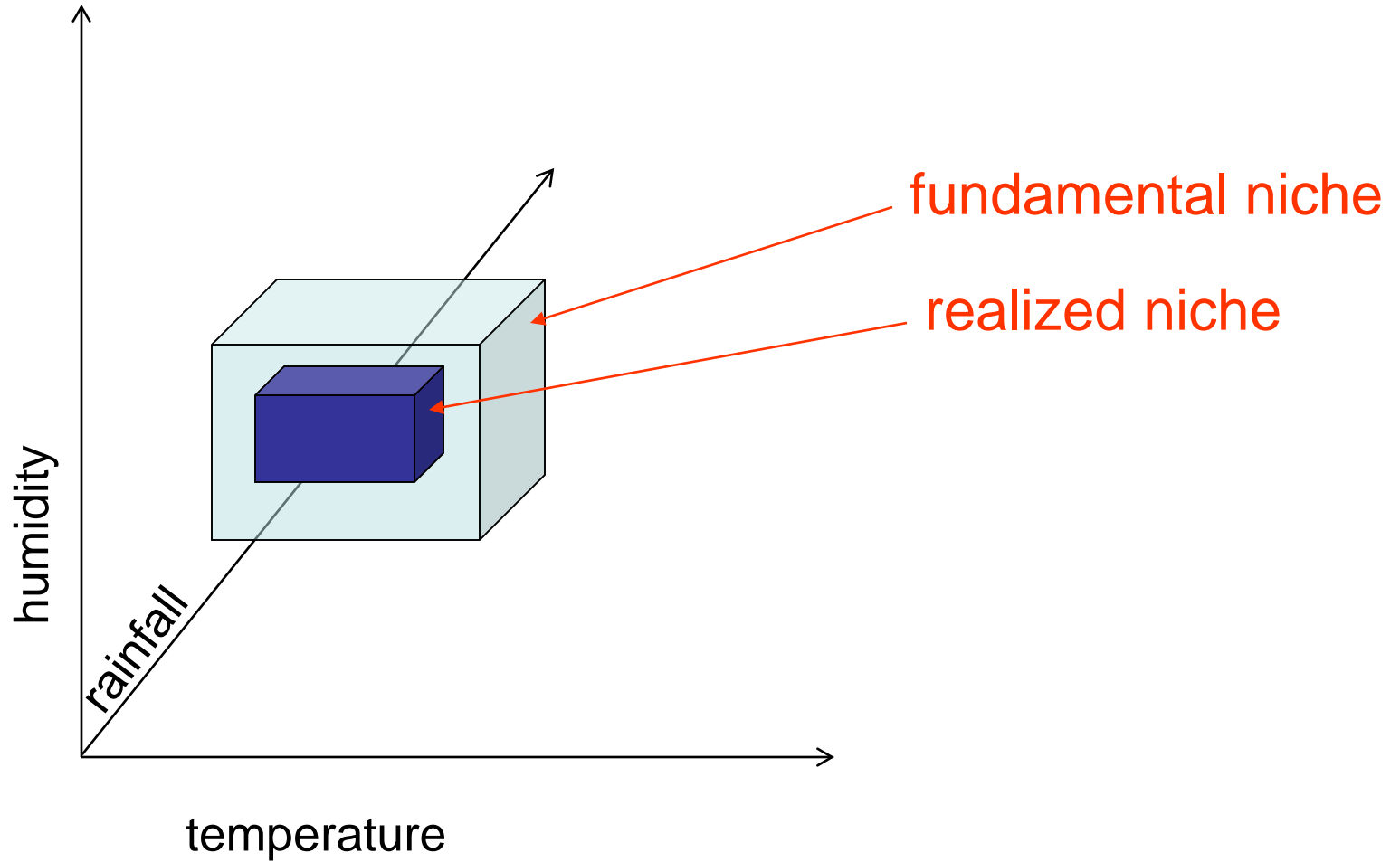
Part I

- What is a mechanistic niche model?
 - Thermodynamic basis to the niche
 - The importance of temperature
 - Heat budgets
 - Microclimates
 - Water budgets
 - Play with NicheMapR
- Biophysical Ecology
- 

Part II

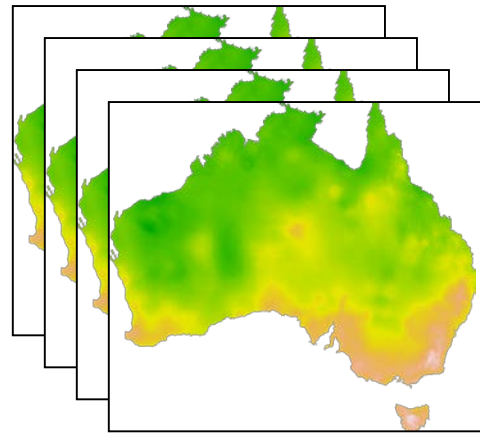
- Connecting to the Dynamic Energy Budget
- Play with NicheMapR
- Inferring climatic constraints
- Nutritional constraints

What is a mechanistic niche model?



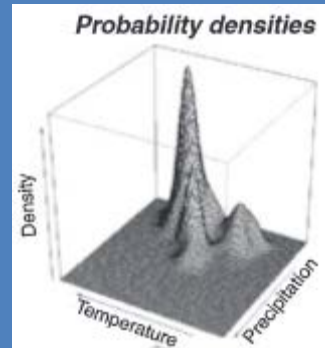
What is a mechanistic niche model?

Environmental Layers

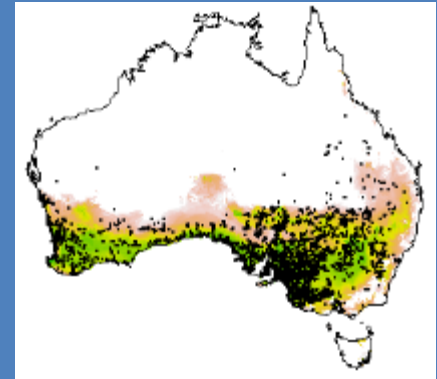


Correlative Model (process implicit)

Maxent model

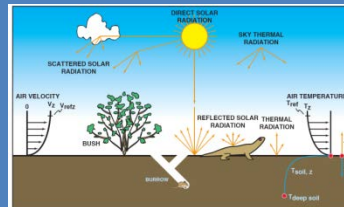


probability of occurrence

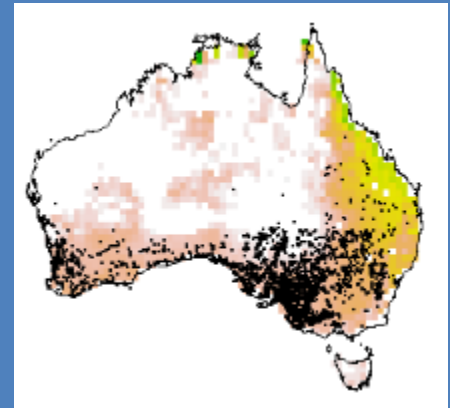


Mechanistic Model (process explicit)

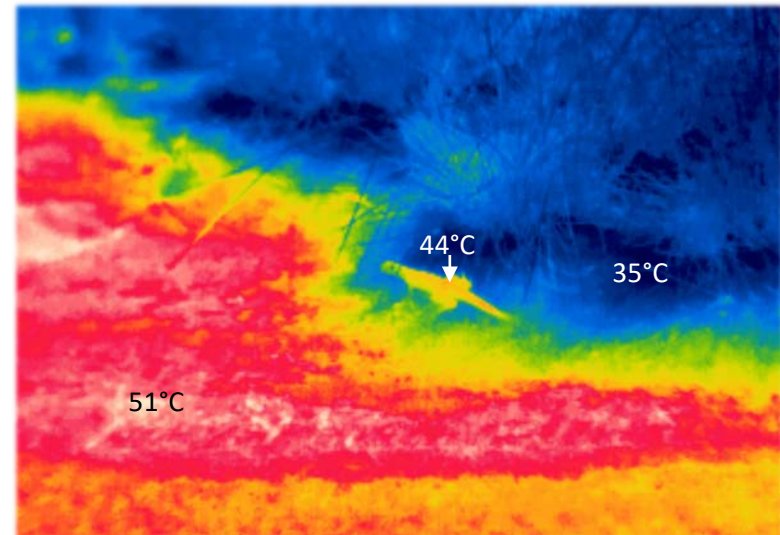
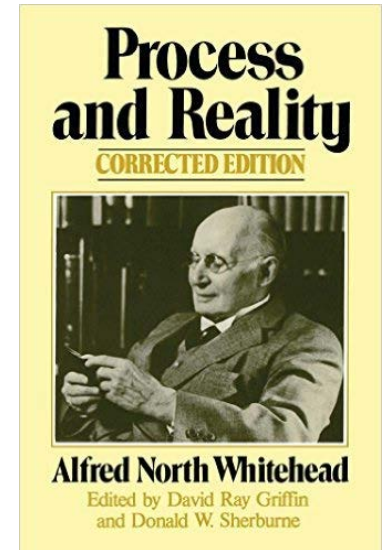
NicheMapR model



potential reproduction



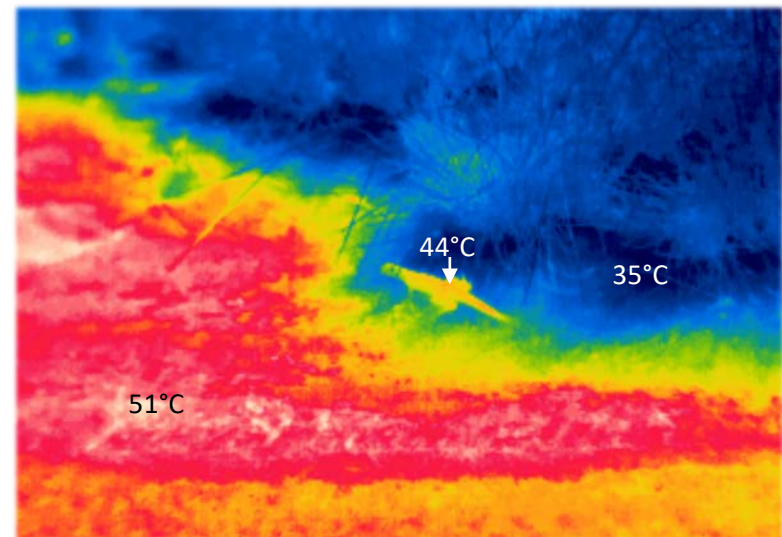
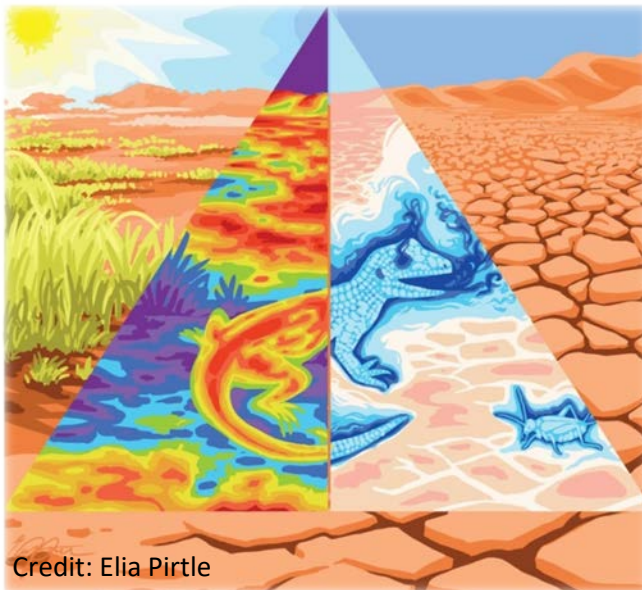
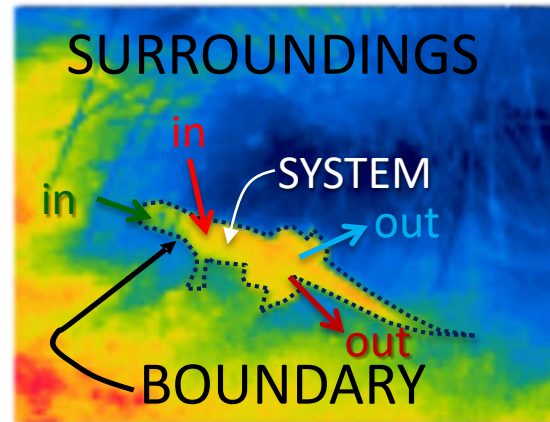
Thermodynamic basis to the niche



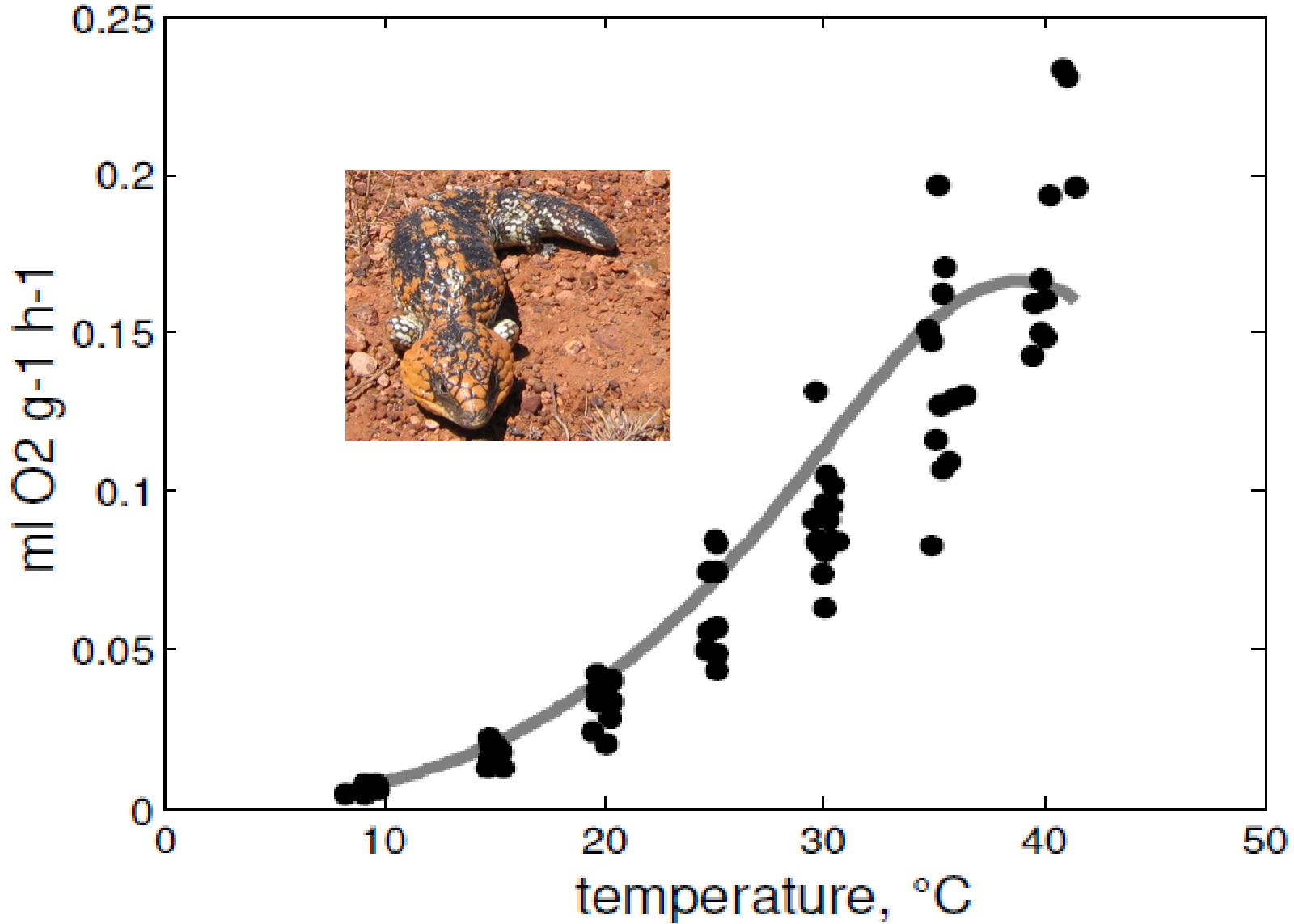
Thermodynamic basis to the niche

energy in =
energy out + energy stored

mass in =
mass out + mass stored

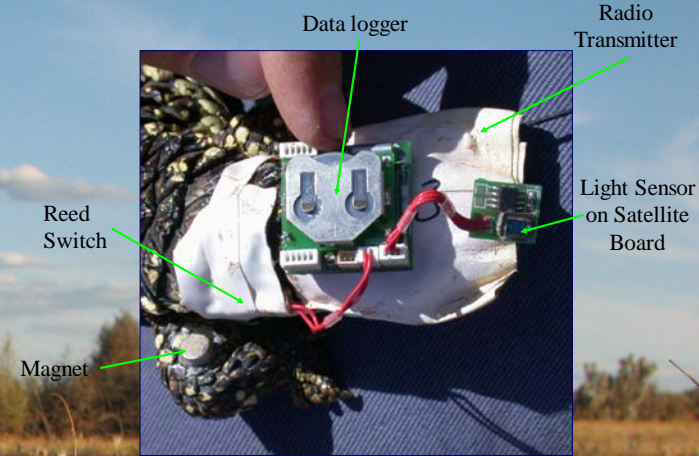


The importance of temperature

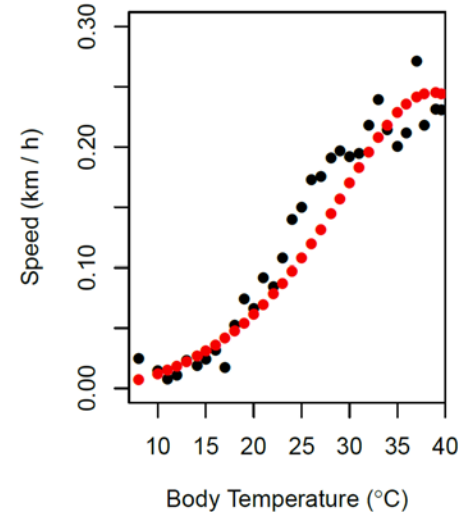
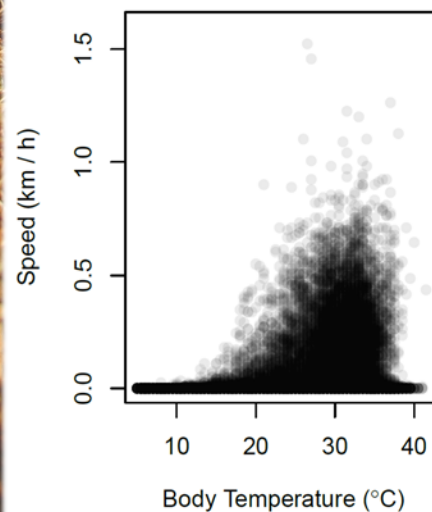


The importance of temperature

The 'waddleometer'

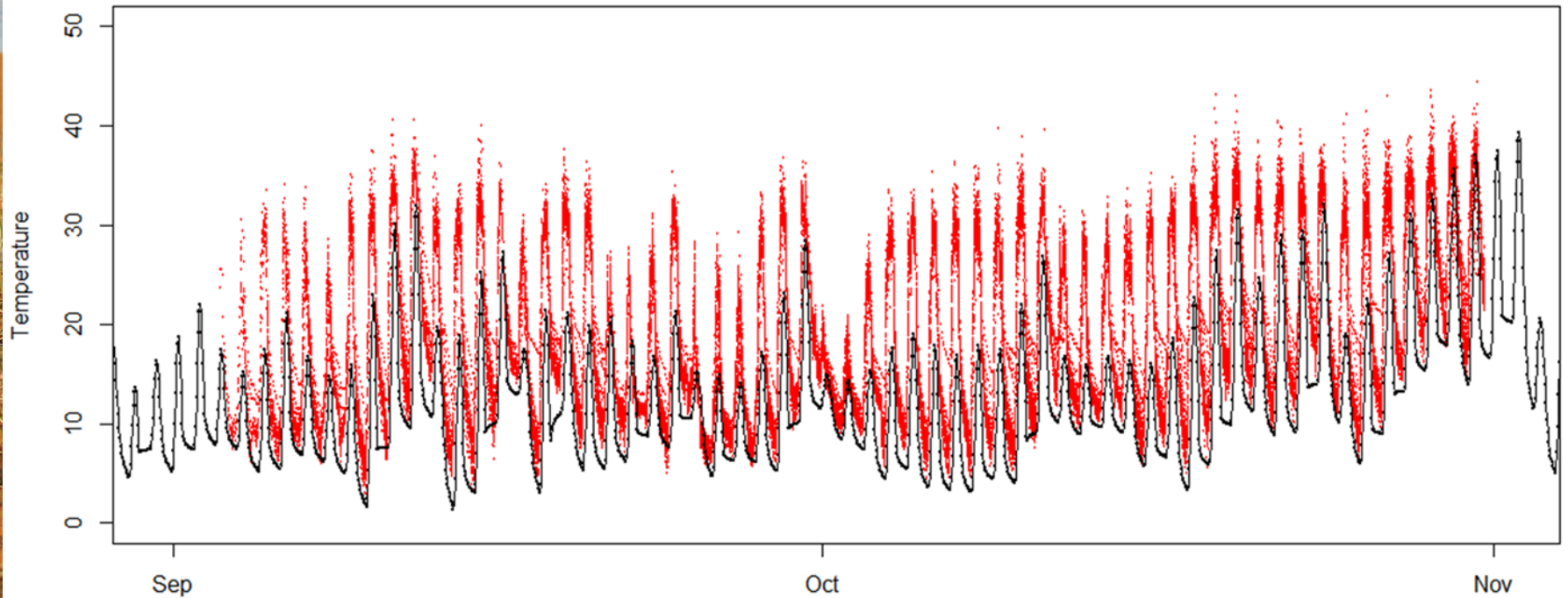


Prof. Mike Bull

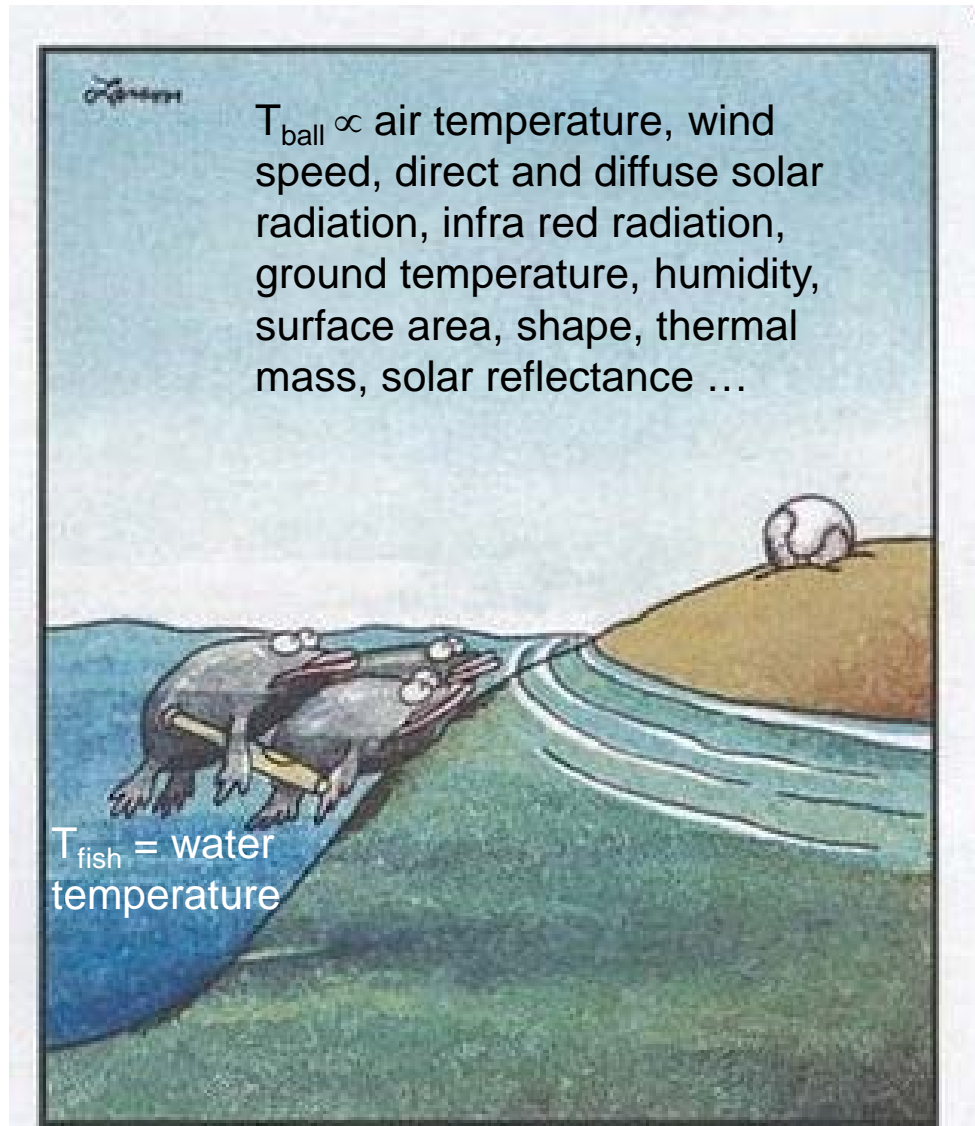


The importance of temperature

60 Lizards' T_b s in 2009



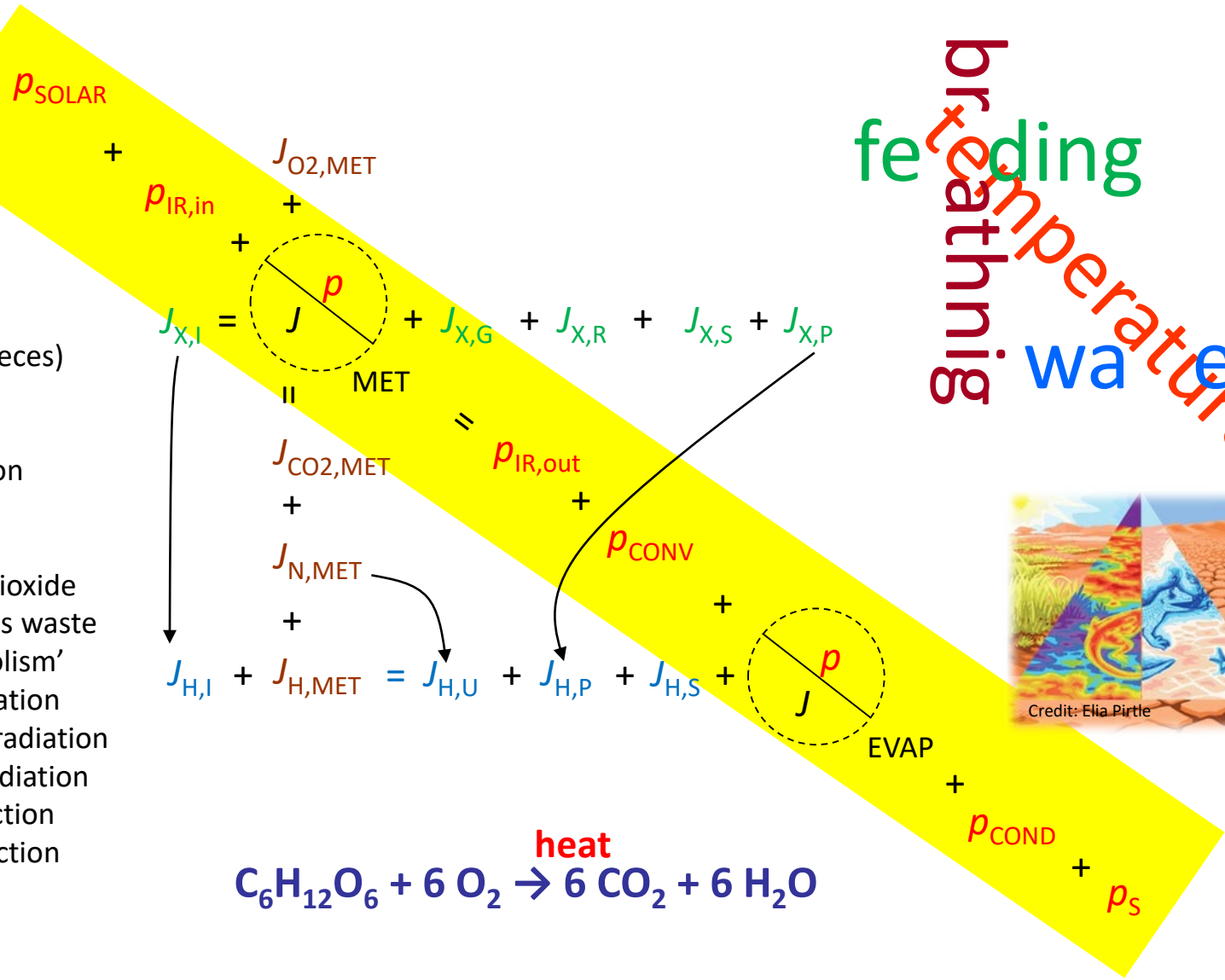
The importance of temperature



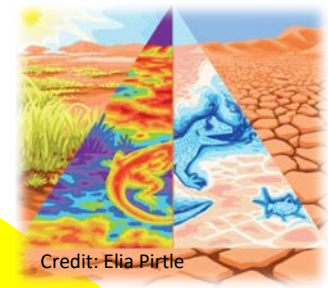
Great moments in evolution

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



breathing temperature
 feeding water
 niche



Biophysical Ecology

THERMODYNAMIC EQUILIBRIA OF ANIMALS WITH ENVIRONMENT¹

WARREN P. PORTER² AND DAVID M. GATES

Missouri Botanical Garden

2315 Tower Grove Avenue, St. Louis, Missouri 63110

and

Washington University, St. Louis, Missouri 63130

Ecological Monographs **39**(3), 227-244 (1969)



Warren Porter
University of Wisconsin,
Madison

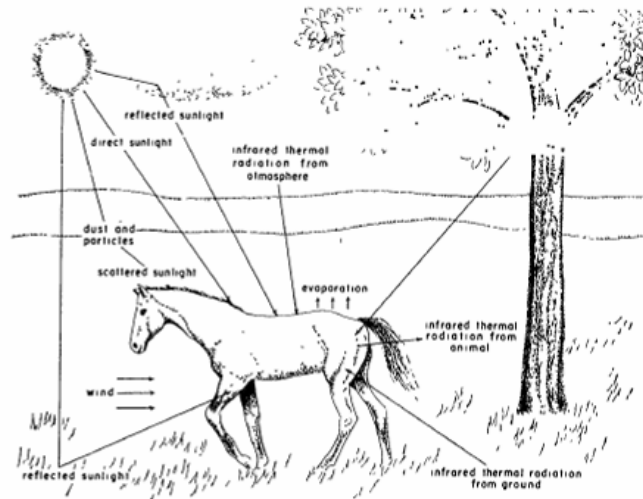
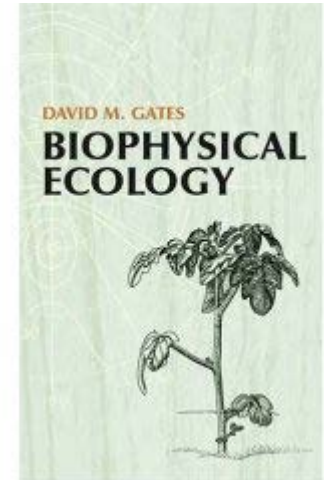


FIG. 1. Streams of energy between an animal and the environment.



Biophysical Ecology – Heat Budgets

(Heat) Energy Balance of a Lizard

Solar + Infra-red =
 (gained) (gained)

Infra-red + Convection
 (lost) (gained/lost)

$$Q_a - \underbrace{\sigma [T_b + 273]^4}_{\substack{\text{infra-red radiation} \\ \text{lost}}} - \overbrace{h_c [T_b - T_a]}^{\text{convection}} = 0$$

Q_a → infra-red and solar radiation gained
 T_b → body temperature
 T_a → air temperature
 h_c → wind speed V , organism size D
 $h_c = 3.49 \frac{V^{0.5}}{D^{0.5}}$

Biophysical Ecology – Heat Budgets

What would the body temperature be if ...?



Diameter = 0.015 m

Wind speed = 2.0 m/s

Air temperature = 20 °C

Radiation = 700 W/m²

$T_b = 26$ °C

If we know the environmental conditions, we can find the body temperature which satisfies the energy balance equation

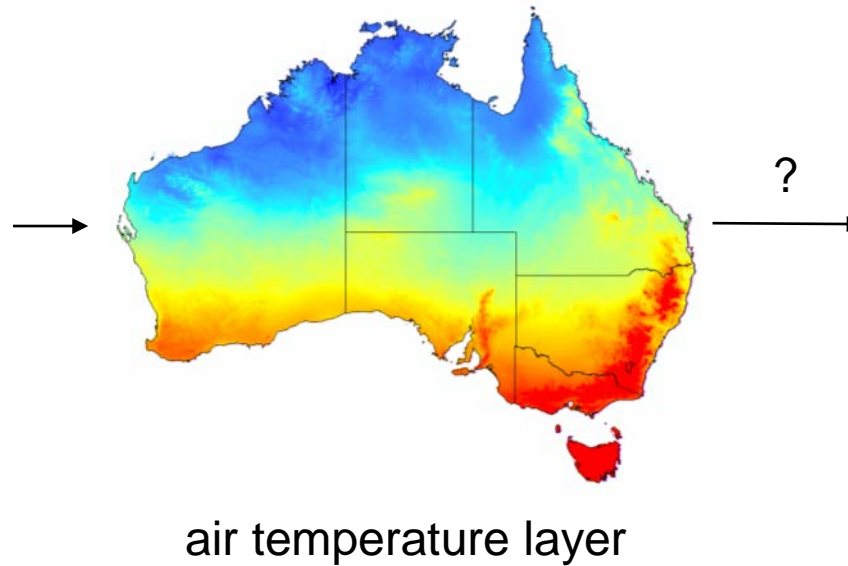
$$Q_a - \sigma[T_b + 273]^4 - 3.49 \frac{V^{0.5}}{D^{0.5}} [T_b - T_a] = 0$$

$$700 - \sigma[T_b + 273]^4 - 3.49 \frac{2.0^{0.5}}{0.015^{0.5}} [T_b - 20] = 0$$

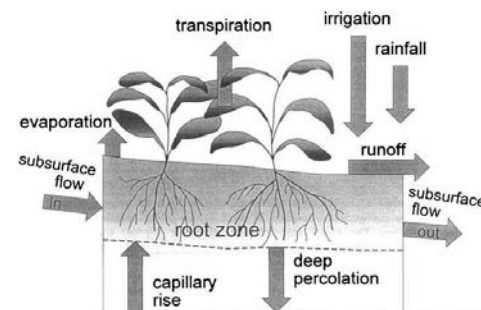
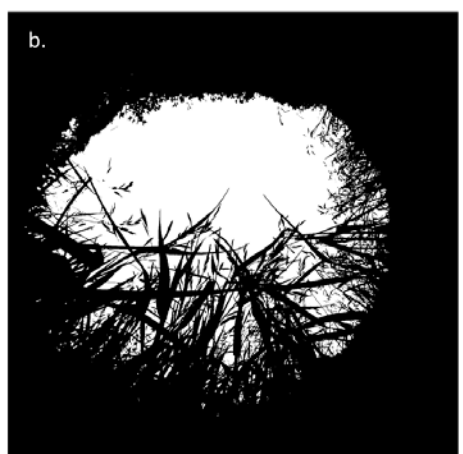
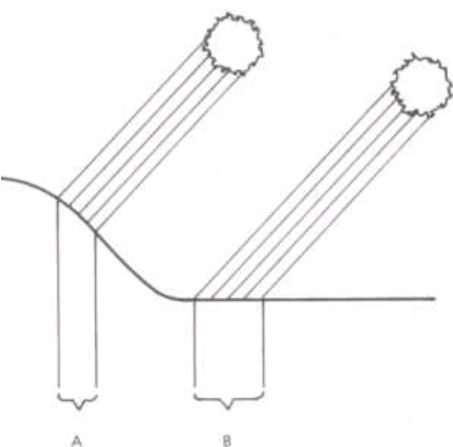
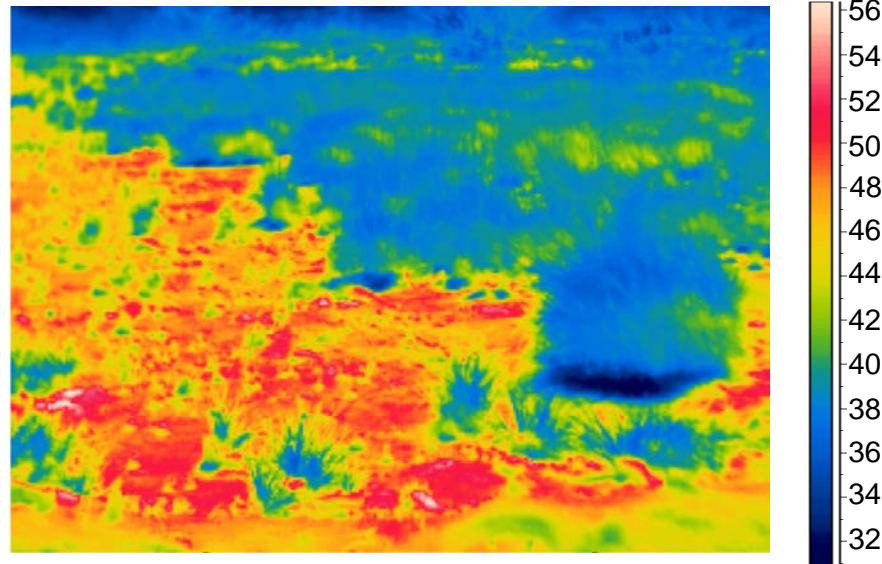
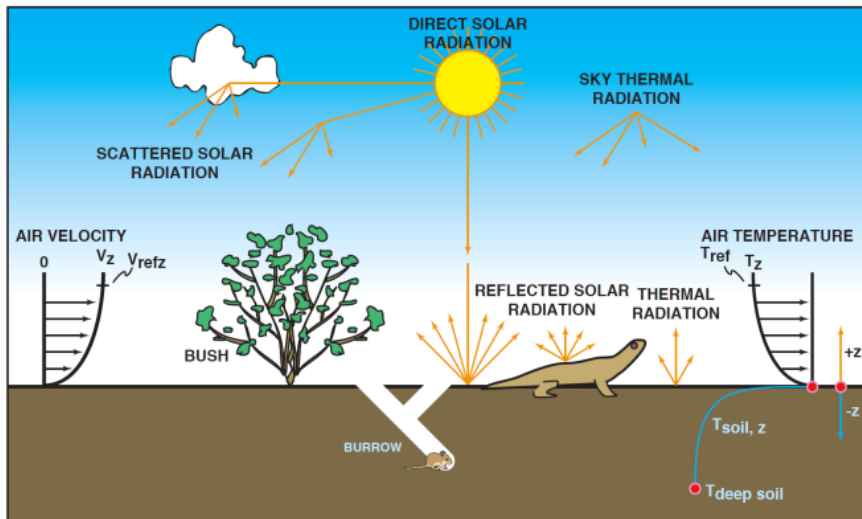
Biophysical Ecology – Microclimates



weather station

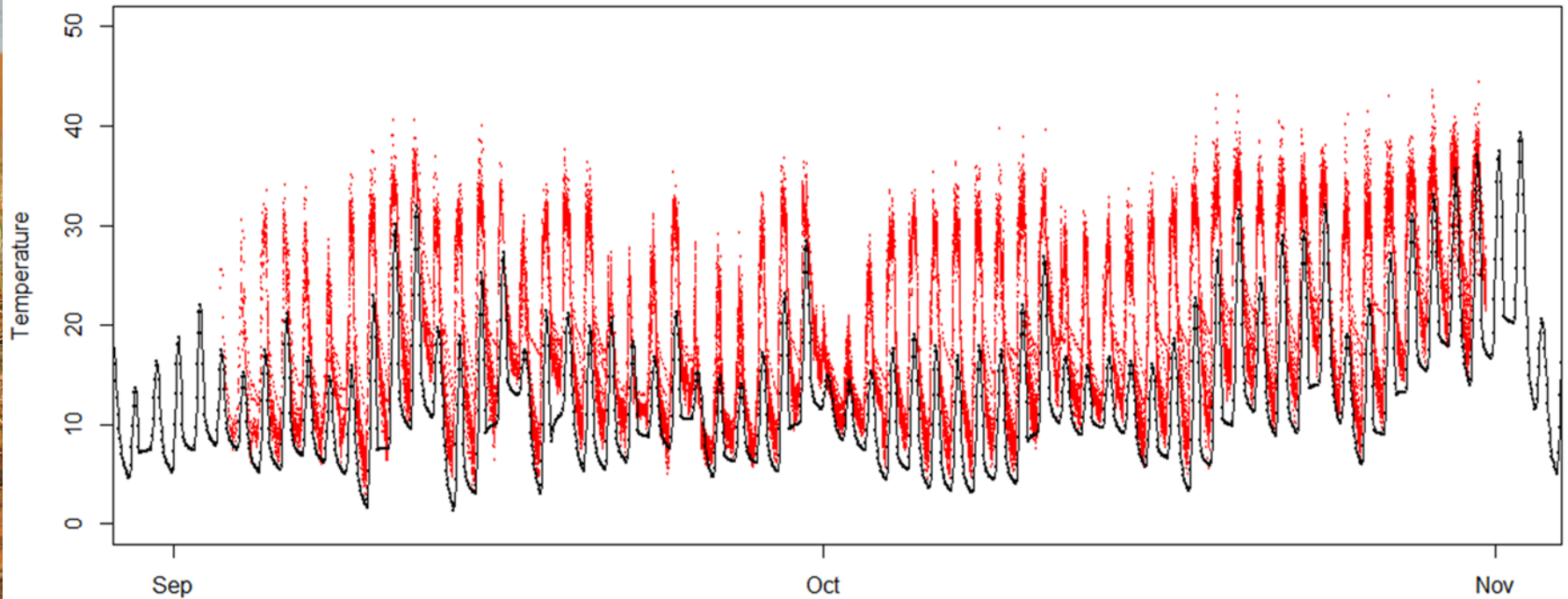


Biophysical Ecology – Microclimates



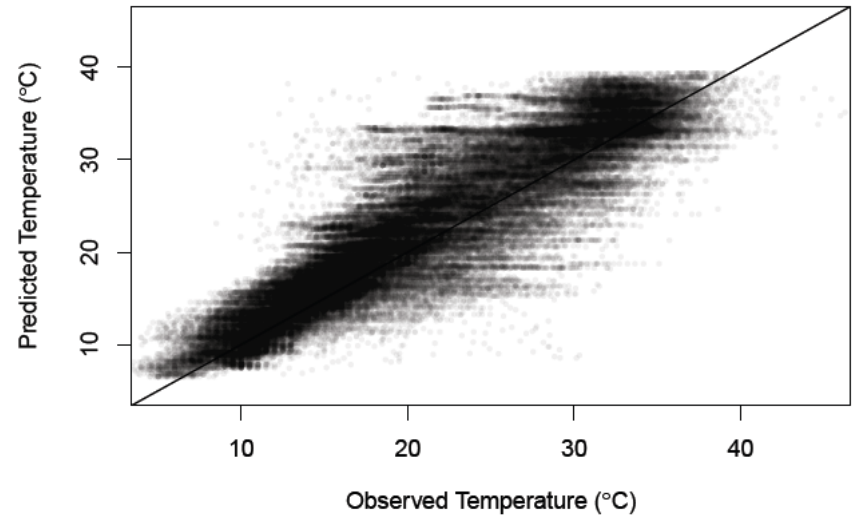
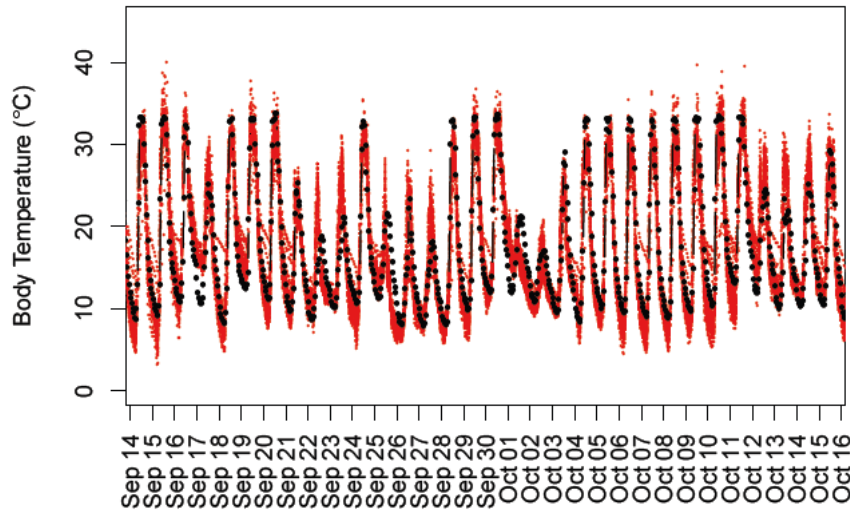
Biophysical Ecology – Heat Budgets

60 Lizards' T_b s in 2009

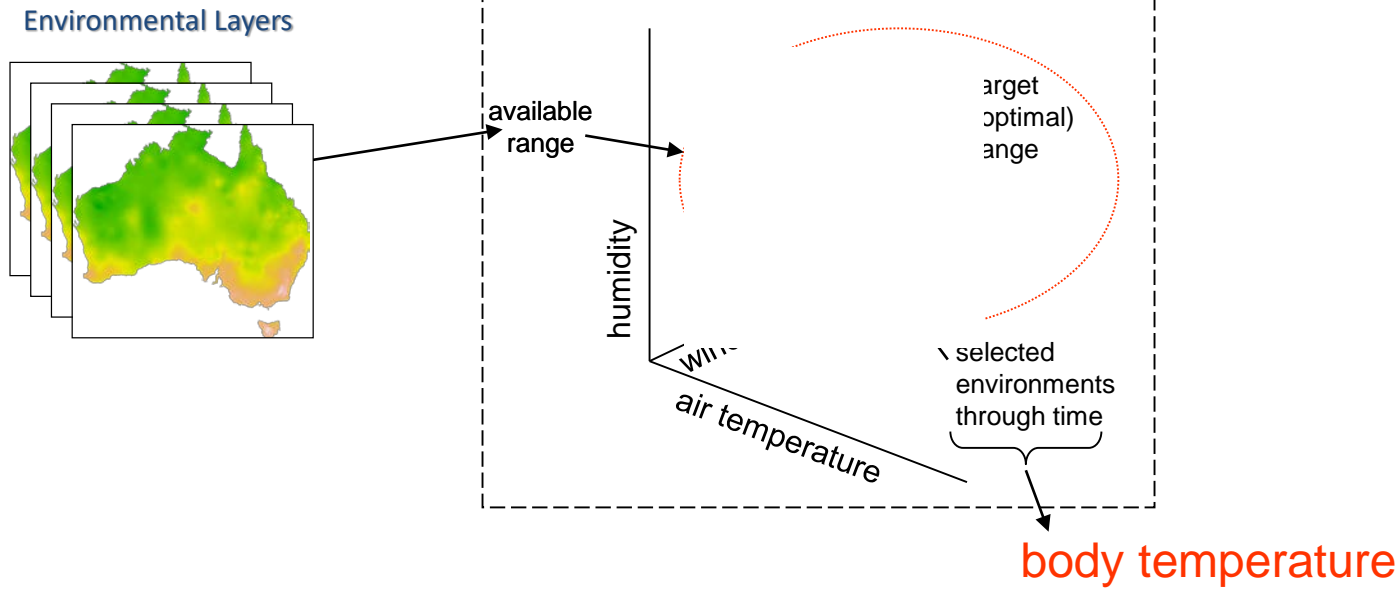


Biophysical Ecology – Heat Budgets

60 Lizards' T_b s in 2009

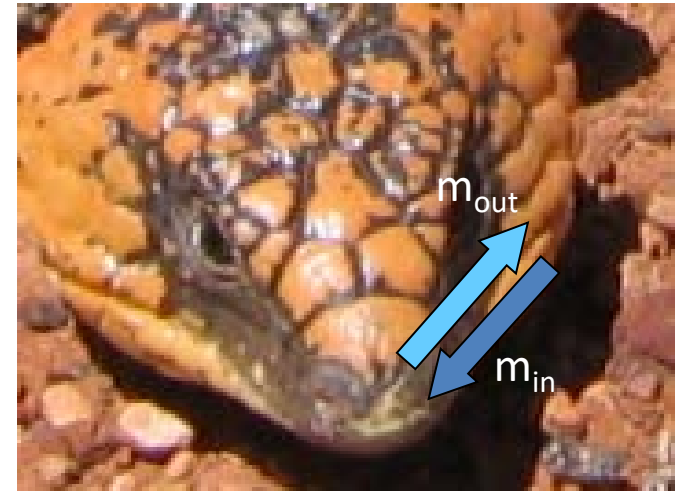
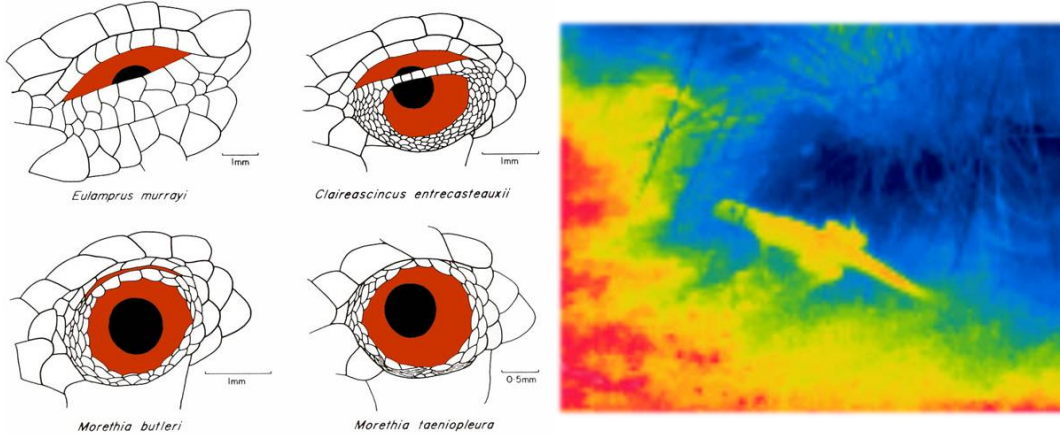


Thermodynamic basis to the niche



Water budget - evaporation

Greer 1989 Biology and Evolution of Australian Lizards



$$Q_{evap,cut} = A_{evap} h_d (V_{d,skin} - V_{d,air}) \lambda$$

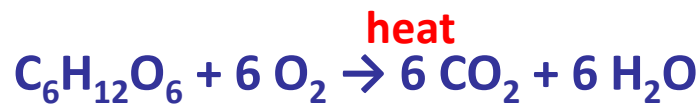
area wet, m^2 → A_{evap}
 mass transfer coefficient → h_d
 vapor density, → $V_{d,skin}$ and $V_{d,air}$
 latent heat of vaporisation, → λ

$$Q_{evap,resp} = \lambda(m_{out,resp} - m_{in,resp})$$

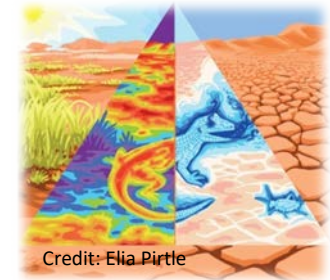
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- N = nitrogenous waste
- MET** = 'metabolism'
- EVAP** = evaporation
- SOLAR** = solar radiation
- IR** = infrared radiation
- CONV** = convection
- COND** = conduction

$$\begin{aligned}
 & p_{\text{SOLAR}} + p_{\text{IR,in}} + J_{O_2,\text{MET}} + J_{X,I} \\
 & = \underbrace{J}_{\text{MET}} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P} \\
 & = p_{\text{IR,out}} + p_{\text{CONV}} + J_{CO_2,\text{MET}} + J_{N,\text{MET}} + J_{H,I} + J_{H,\text{MET}} \\
 & = J_{H,U} + J_{H,P} + J_{H,S} + \underbrace{J}_{\text{EVAP}} + p_{\text{COND}} + p_S
 \end{aligned}$$

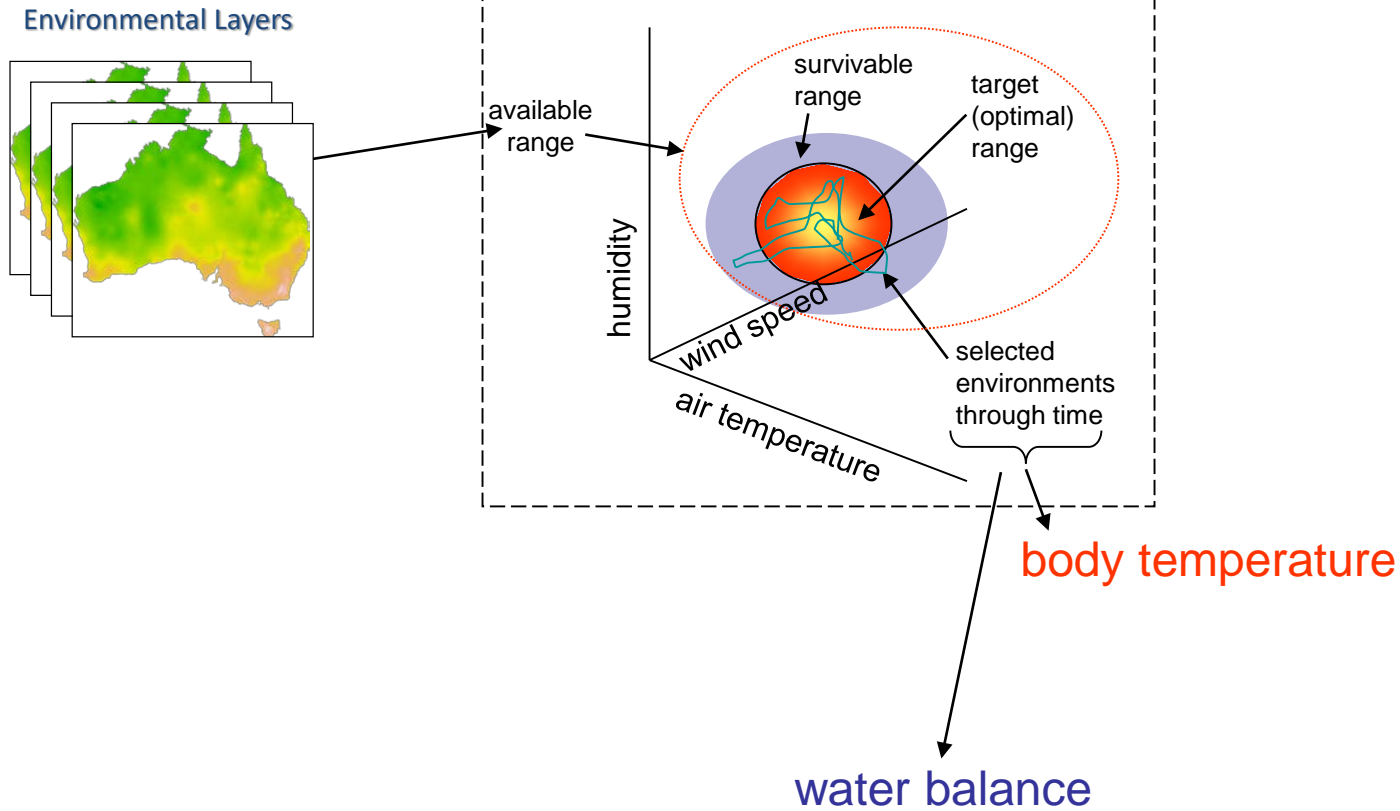


breathing temperature
 water




Credit: Elia Pirtle

Thermodynamic basis to the niche

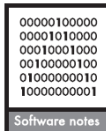
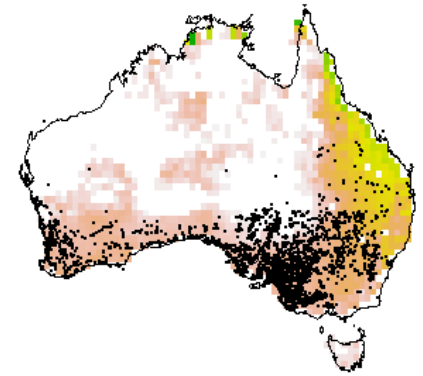
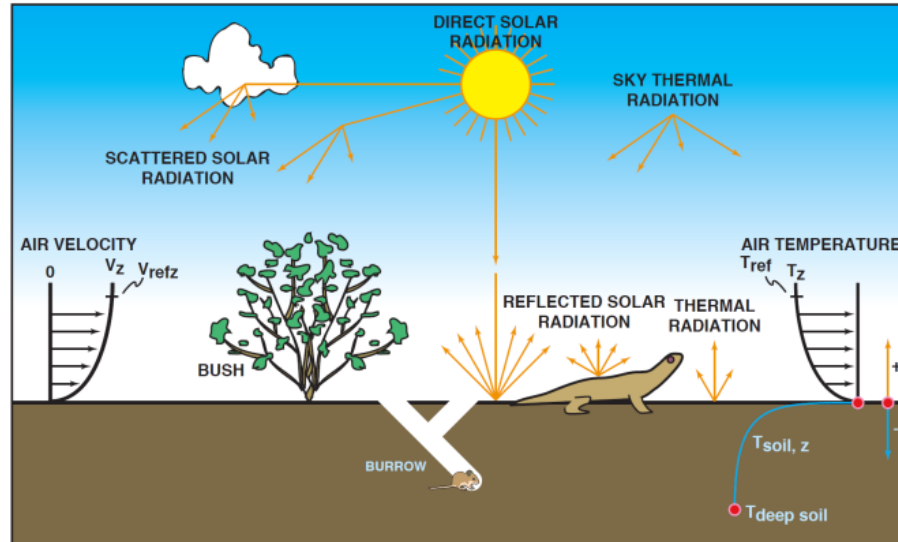
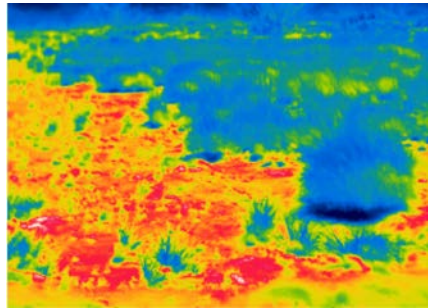


Mechanistic Niche Models

Part I

- What is a mechanistic niche model?
 - Thermodynamic basis to the niche
 - The importance of temperature
 - Heat budgets
 - Microclimates
 - Water budgets
 - Play with NicheMapR
- Biophysical Ecology
- 

NicheMapR – a general system for mechanistic niche modelling



Ecography 40: 664–674, 2017

doi: 10.1111/ecog.02360

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Subject Editor: Brody Sandel. Editor-in-Chief: Miguel Araújo. Accepted 7 August 2016

NicheMapR – an R package for biophysical modelling: the microclimate model

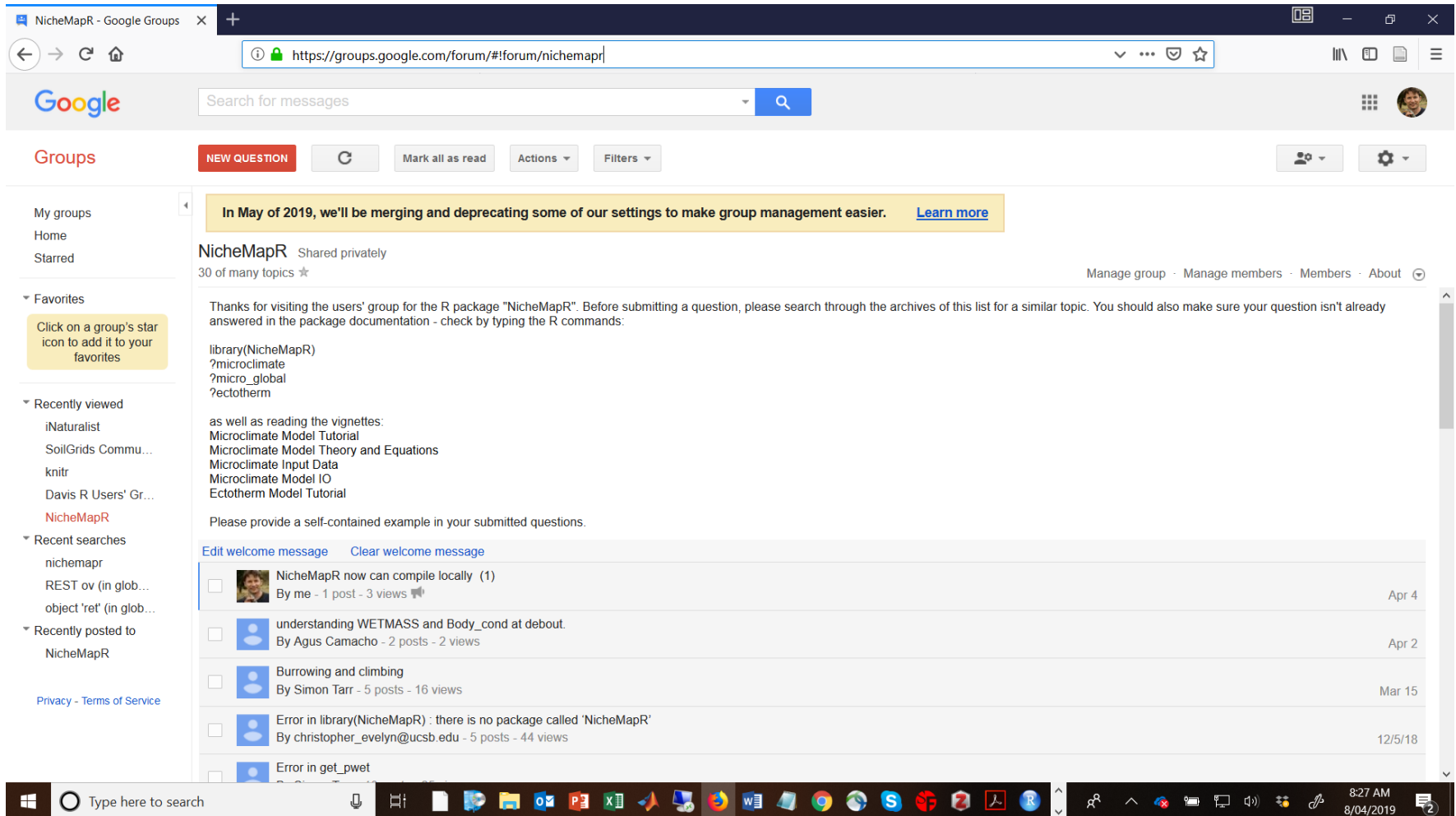
Michael R. Kearney and Warren P. Porter

M. R. Kearney (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.

NicheMapR Google Group

@NicheMapR

<https://groups.google.com/forum/#!forum/nichemapr>



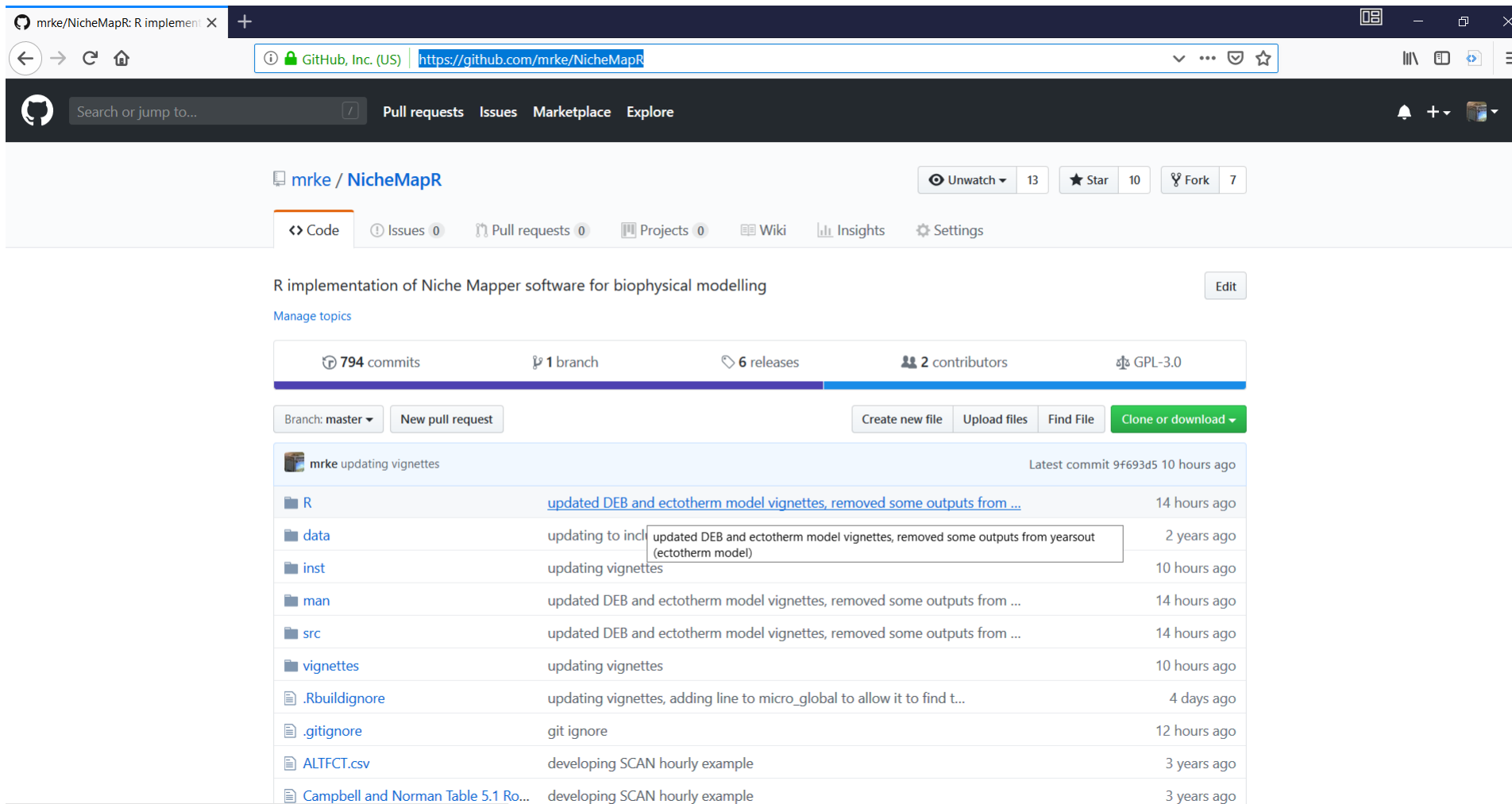
The screenshot shows a web browser window displaying the NicheMapR Google Group forum. The browser's address bar shows the URL <https://groups.google.com/forum/#!forum/nichemapr>. The page features a search bar, navigation buttons like 'NEW QUESTION', and a sidebar with 'My groups' and 'Favorites'. A yellow banner at the top of the forum content area reads: "In May of 2019, we'll be merging and deprecating some of our settings to make group management easier. [Learn more](#)". Below this, the group name "NicheMapR" is shown as "Shared privately" with "30 of many topics" and options to "Manage group", "Manage members", "Members", and "About". The main content area contains a welcome message: "Thanks for visiting the users' group for the R package 'NicheMapR'. Before submitting a question, please search through the archives of this list for a similar topic. You should also make sure your question isn't already answered in the package documentation - check by typing the R commands: library(NicheMapR) ?microclimate ?micro_global ?ectotherm as well as reading the vignettes: Microclimate Model Tutorial Microclimate Model Theory and Equations Microclimate Input Data Microclimate Model IO Ectotherm Model Tutorial Please provide a self-contained example in your submitted questions." Below the welcome message are links to "Edit welcome message" and "Clear welcome message". A list of forum posts follows, including "NicheMapR now can compile locally (1)" by the user "me" (1 post, 3 views, Apr 4), "understanding WETMASS and Body_cond at debut" by Agus Camacho (2 posts, 2 views, Apr 2), "Burrowing and climbing" by Simon Tarr (5 posts, 16 views, Mar 15), "Error in library(NicheMapR) : there is no package called 'NicheMapR'" by christopher_elynn@ucsb.edu (5 posts, 44 views, 12/5/18), and "Error in get_pwet". The Windows taskbar at the bottom shows the search bar, system tray, and the date/time "8:27 AM 8/04/2019".

NicheMapR Google Group

@NicheMapR



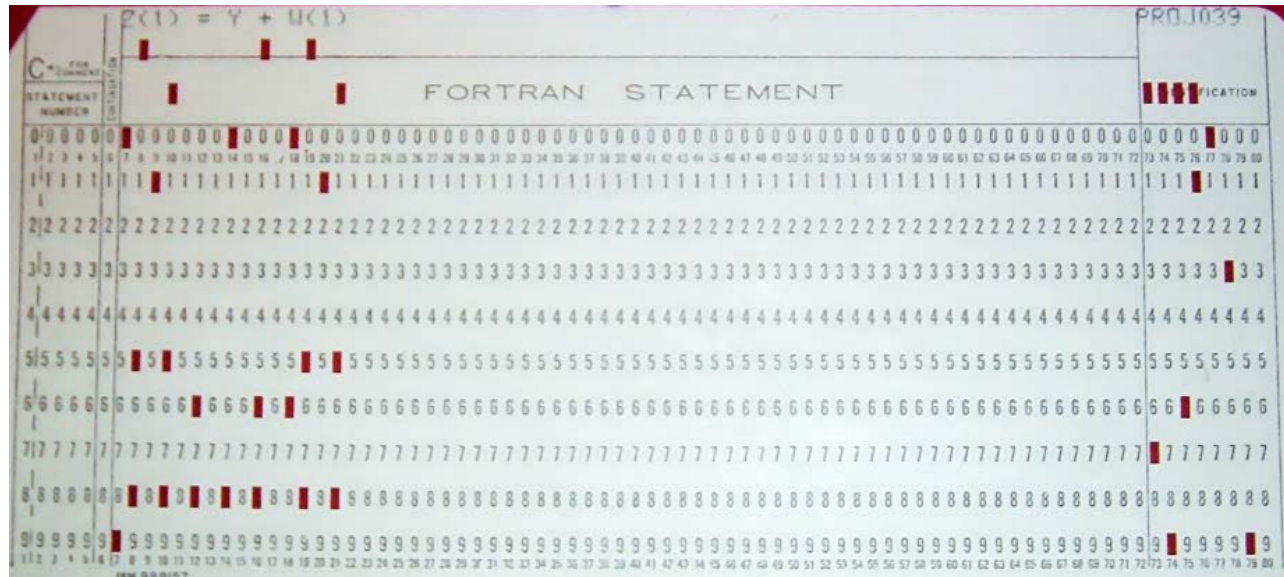
<https://github.com/mrke/NicheMapR>



The screenshot shows the GitHub repository page for `mrke/NicheMapR`. The repository is described as "R implementation of Niche Mapper software for biophysical modelling". It has 794 commits, 1 branch, 6 releases, 2 contributors, and is licensed under GPL-3.0. The page shows a list of recent commits, with the most recent one being "mrke updating vignettes" from 10 hours ago. A tooltip is visible over the commit message "updated DEB and ectotherm model vignettes, removed some outputs from yearsout (ectotherm model)".

Commit Message	Time Ago
mrke updating vignettes	10 hours ago
R updated DEB and ectotherm model vignettes, removed some outputs from ...	14 hours ago
data updating to include updated DEB and ectotherm model vignettes, removed some outputs from yearsout (ectotherm model)	2 years ago
inst updating vignettes	10 hours ago
man updated DEB and ectotherm model vignettes, removed some outputs from ...	14 hours ago
src updated DEB and ectotherm model vignettes, removed some outputs from ...	14 hours ago
vignettes updating vignettes	10 hours ago
.Rbuildignore updating vignettes, adding line to micro_global to allow it to find t...	4 days ago
.gitignore git ignore	12 hours ago
ALTFCT.csv developing SCAN hourly example	3 years ago
Campbell and Norman Table 5.1 Ro... developing SCAN hourly example	3 years ago

NicheMapR



Niche Mapper

Fortran

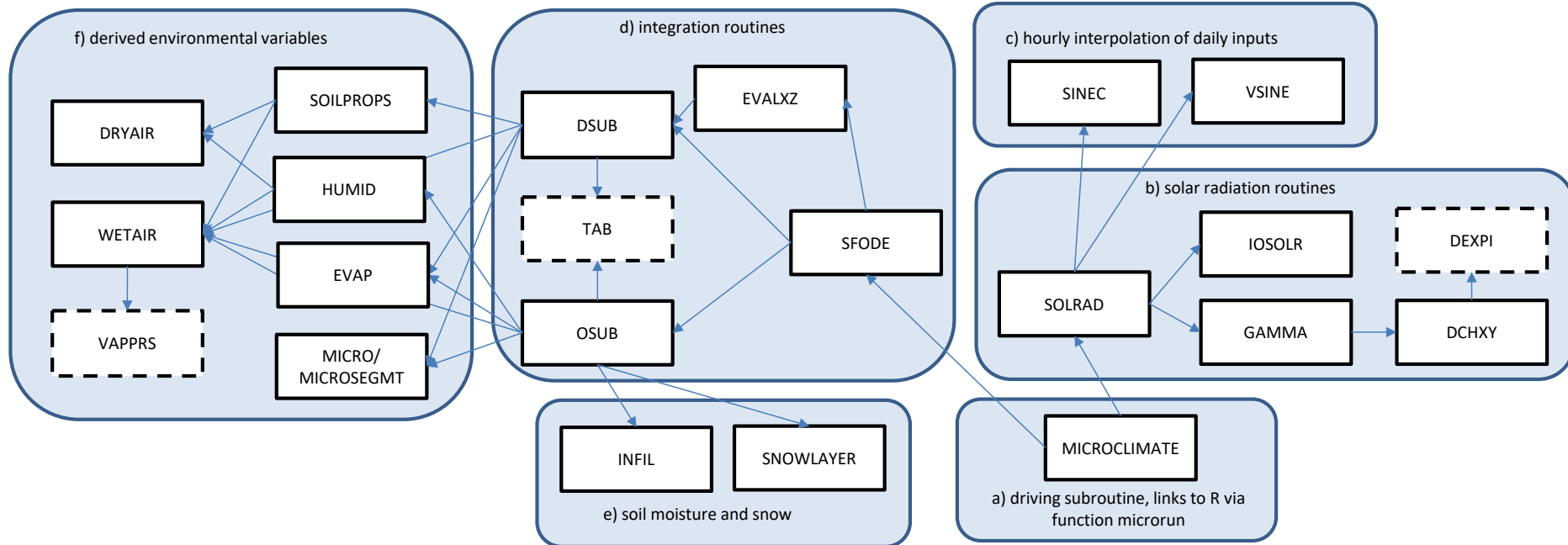
Microclimate Program Structure

Niche Mapper

Fortran

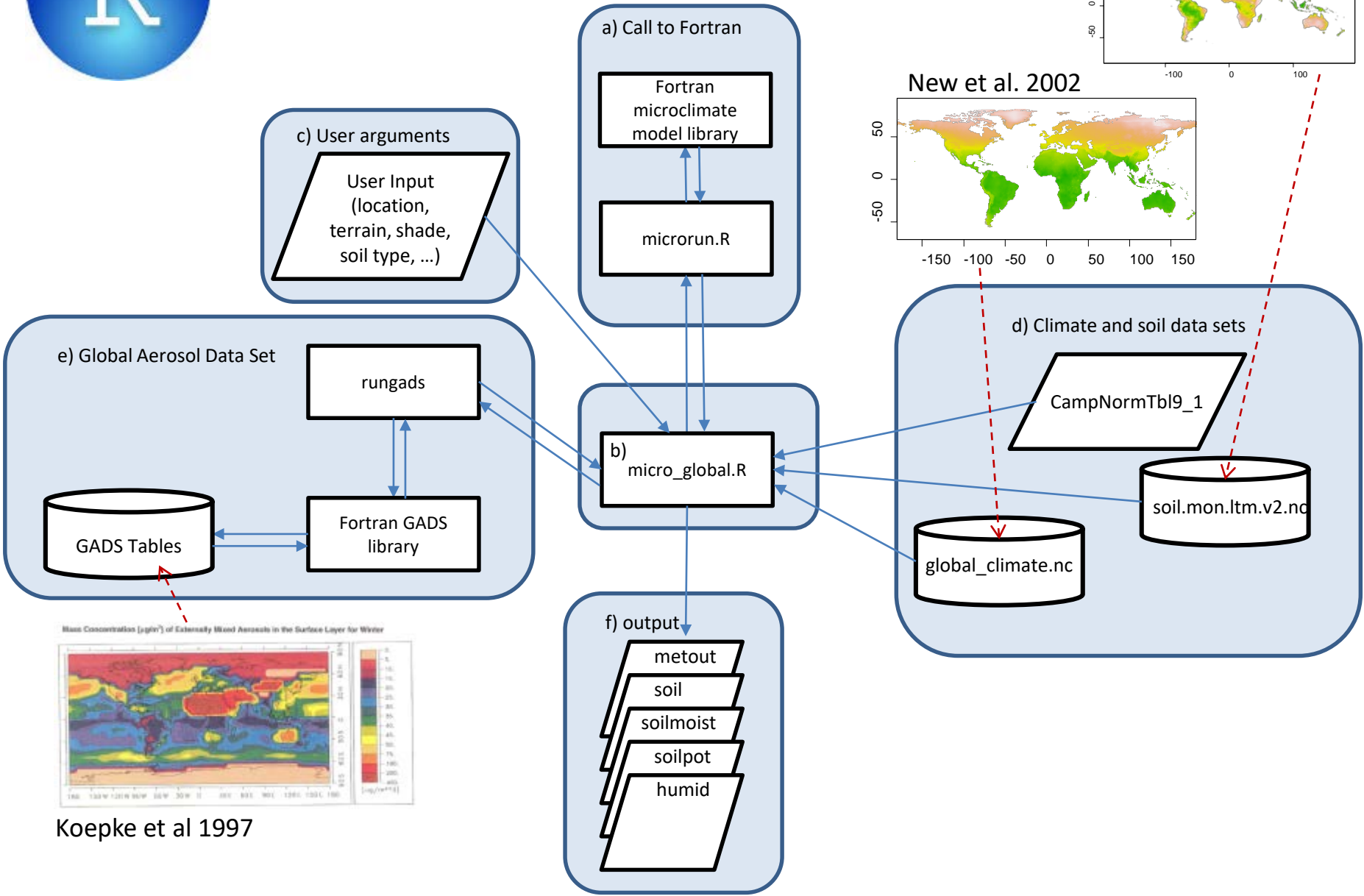


NicheMapR

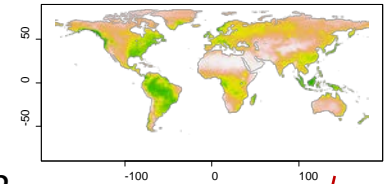




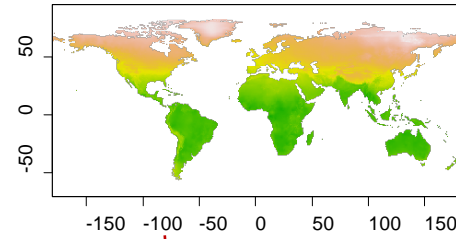
NicheMapR



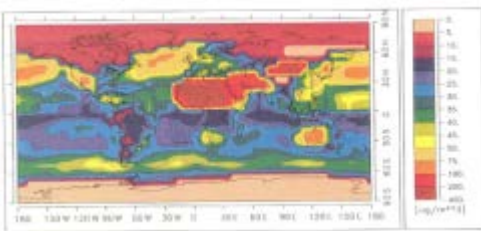
CPC soil moisture



New et al. 2002



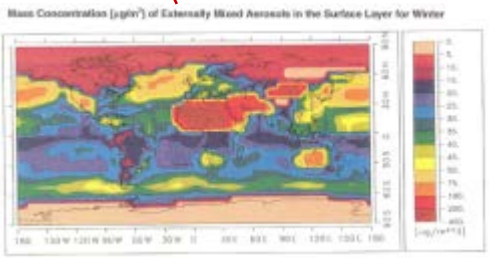
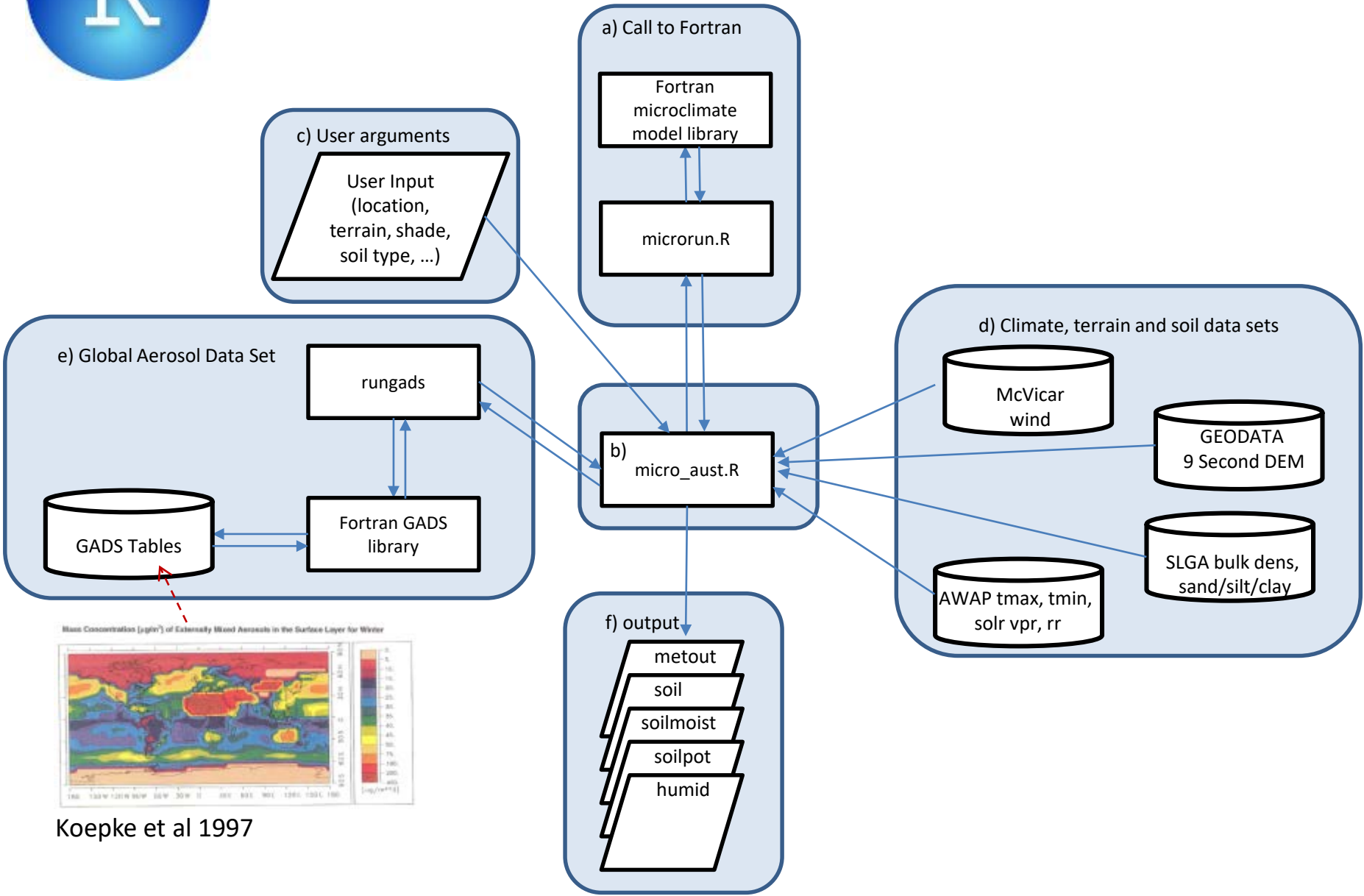
Mass Concentration ($\mu\text{g}/\text{m}^3$) of Externally Mixed Aerosols in the Surface Layer for Winter



Koepke et al 1997

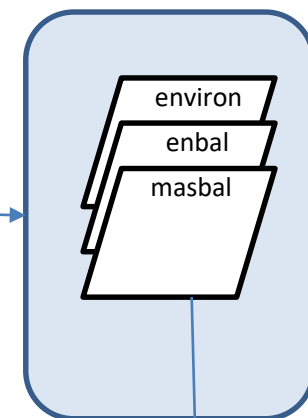
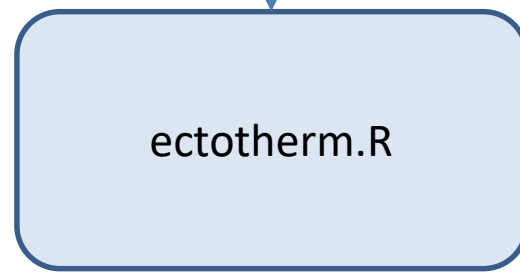
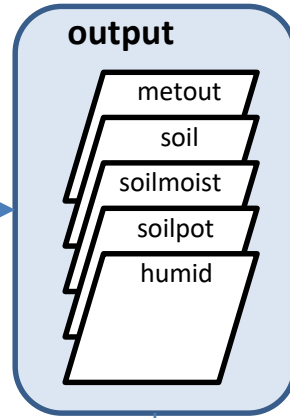
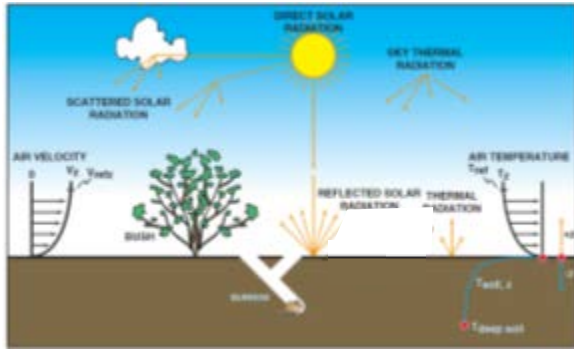


NicheMapR

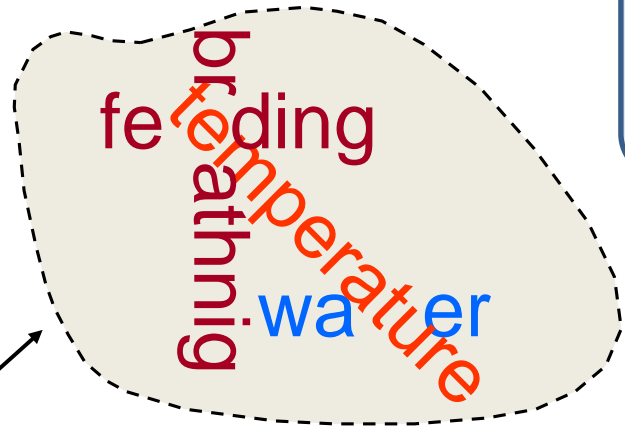


Koepke et al 1997

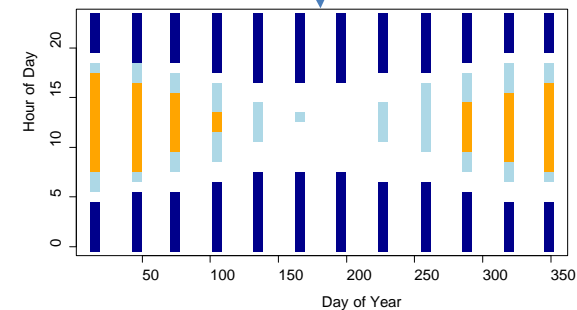
The Heat and Water Budget Model



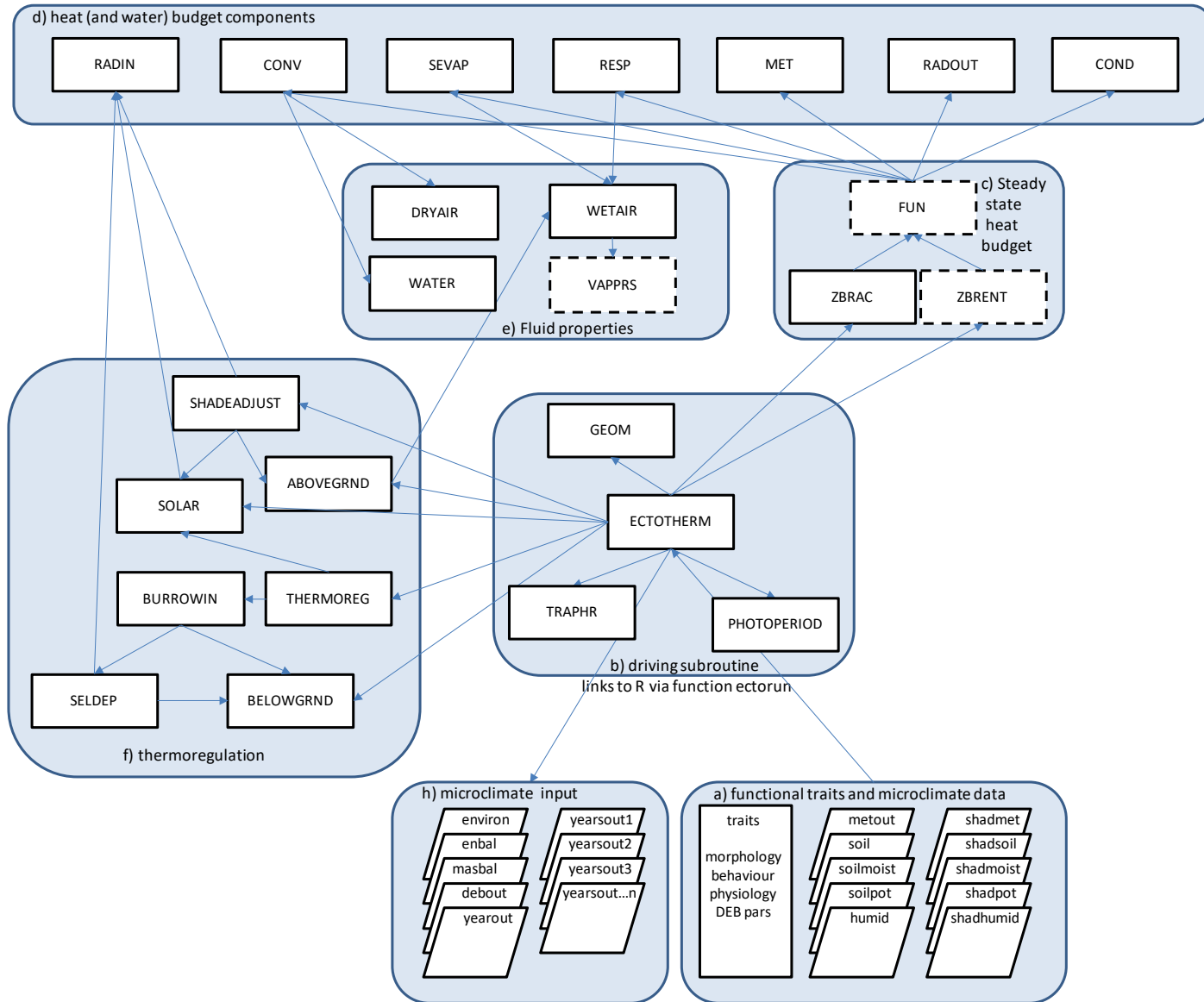
SURROUNDINGS



BOUNDARY

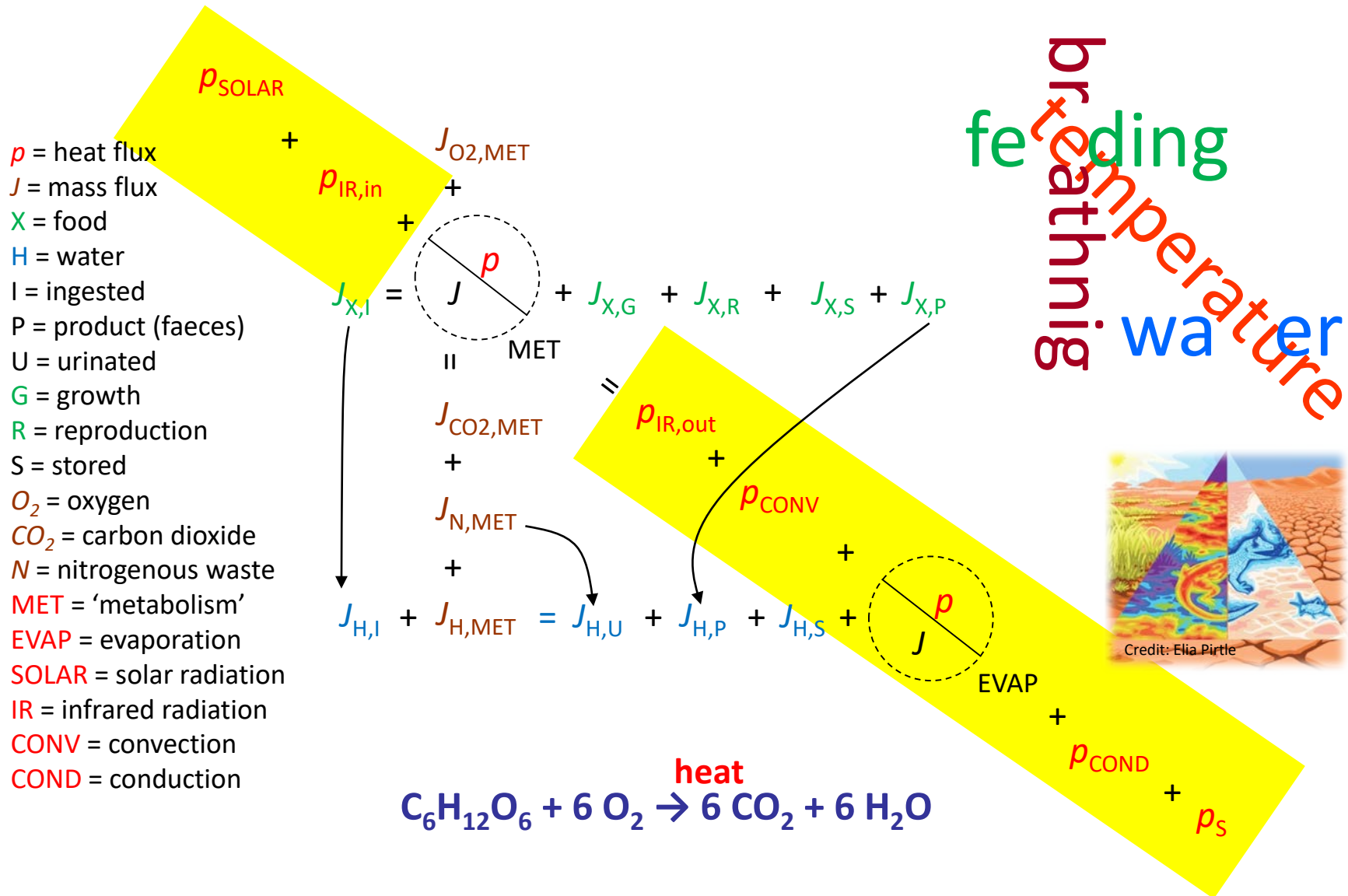


The Heat and Water Budget Model

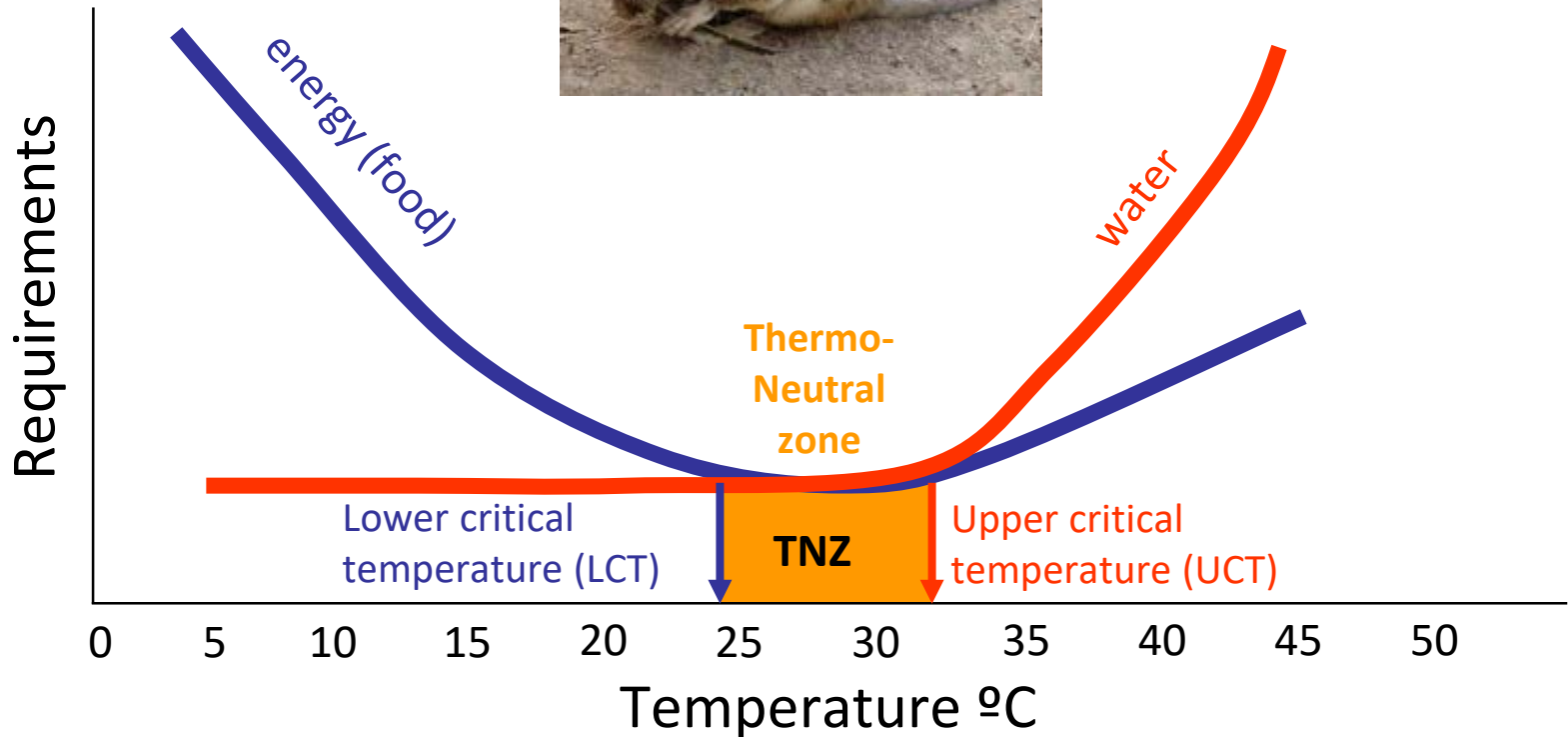


Thermodynamic basis to the niche

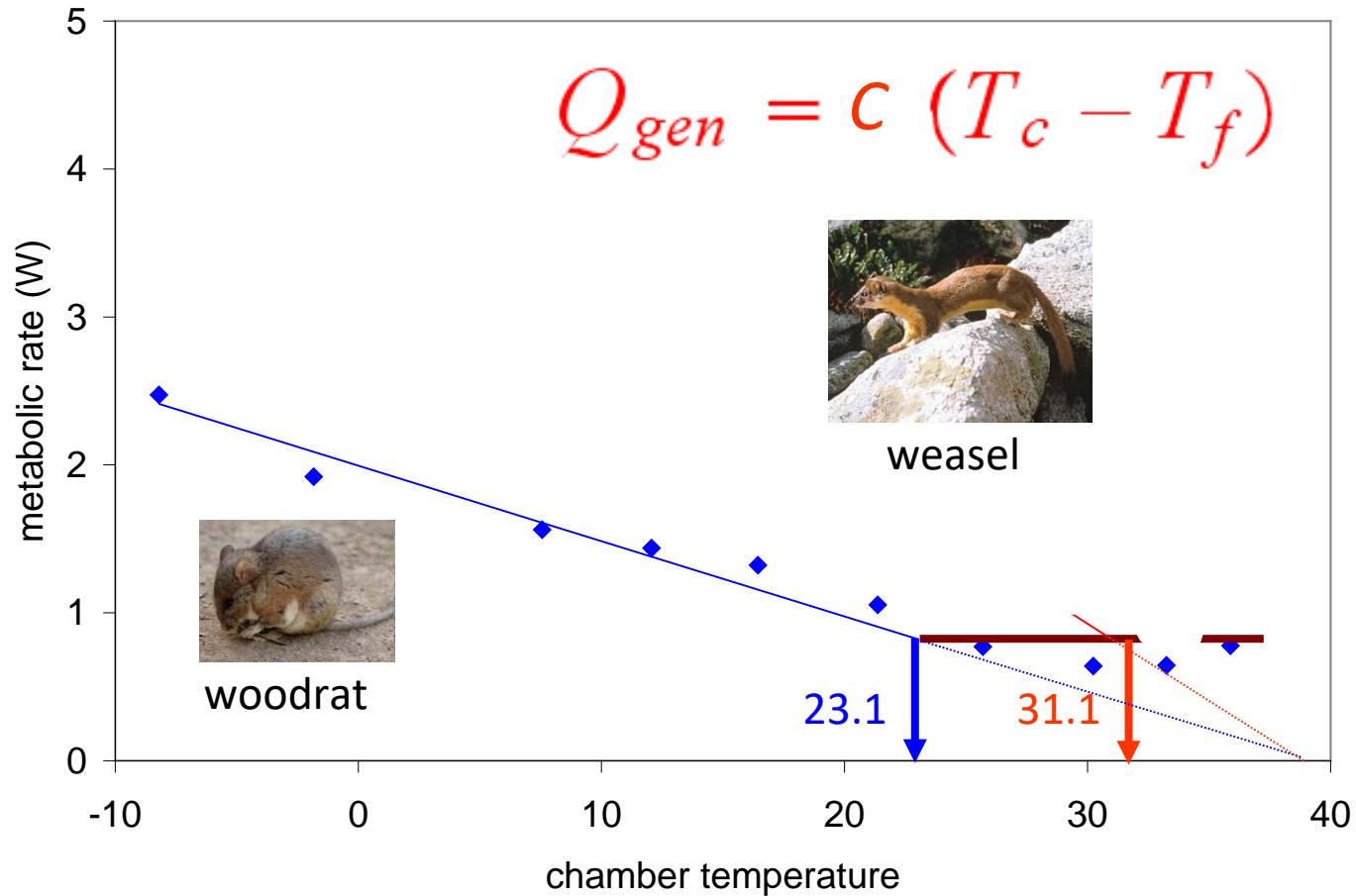
- p = heat flux
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Biophysical Ecology – Heat Budgets

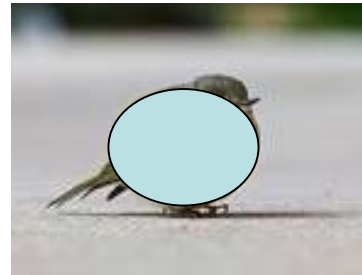
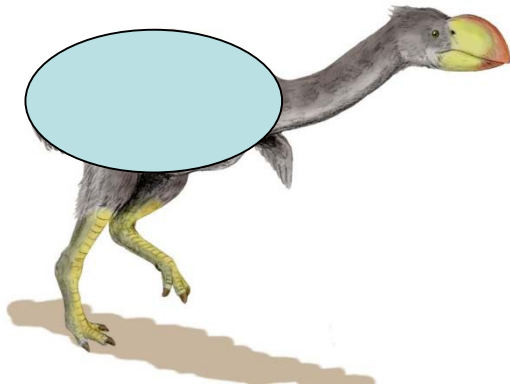
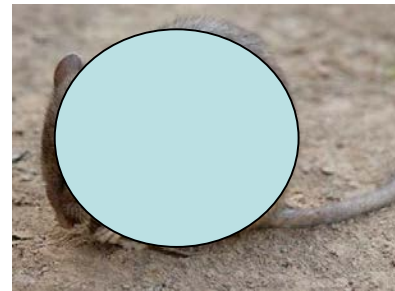
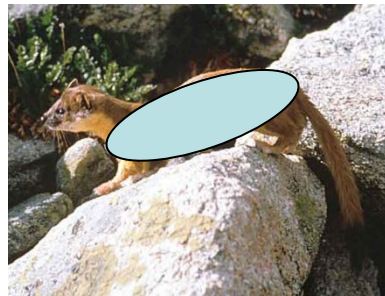
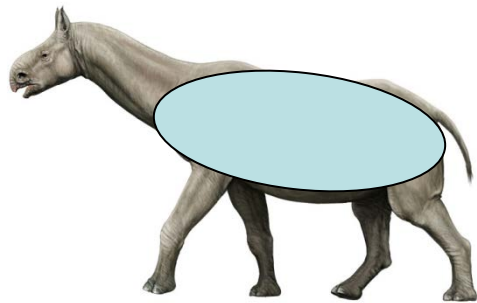


Biophysical Ecology – Heat Budgets



Predicting Endotherm Energy and Water Requirements

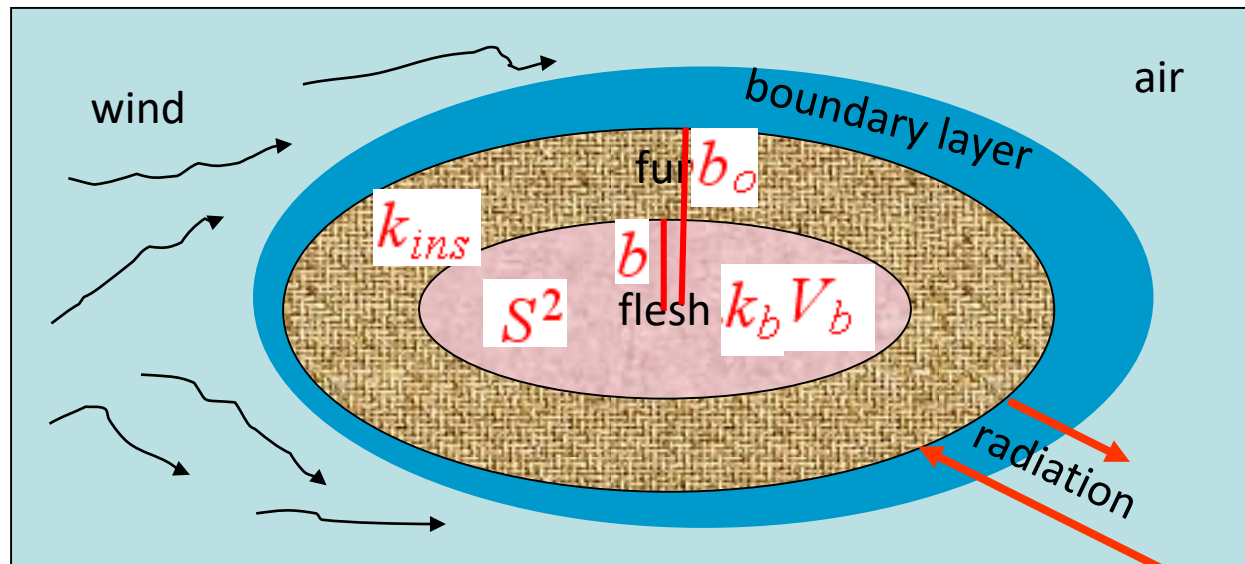
consider an elliptical animal



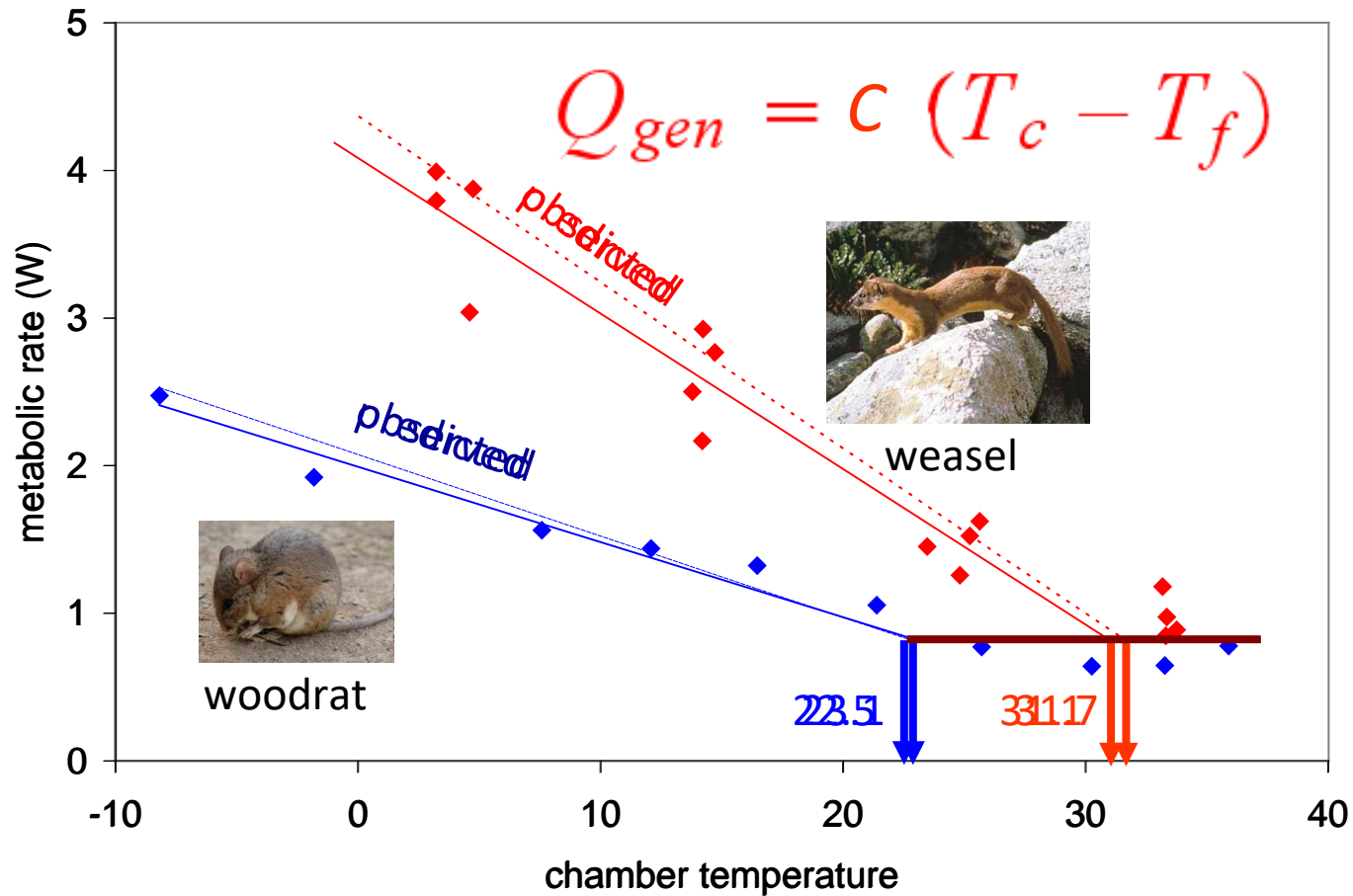
Predicting Endotherm Energy and Water Requirements

heat energy balance of an endotherm

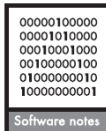
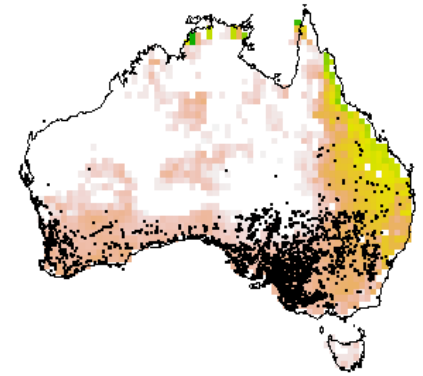
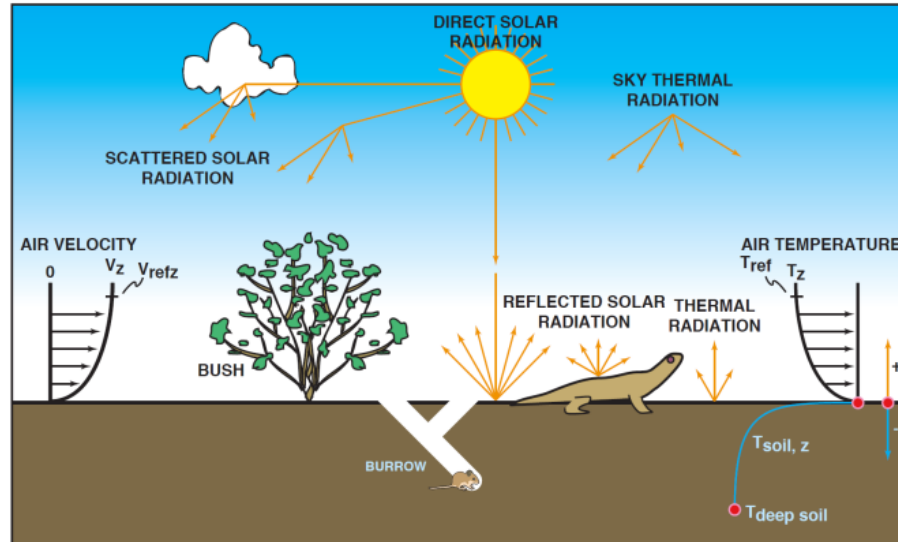
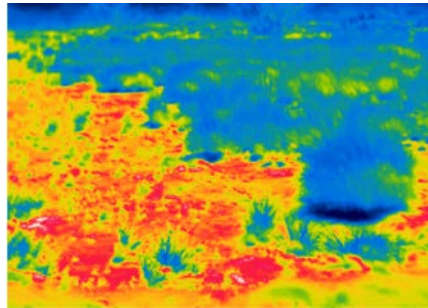
$$Q_{gen} = \frac{C (T_c - T_f)}{\text{body resistance} + \text{fur resistance} + \text{environmental resistance}}$$



Predicting Endotherm Energy and Water Requirements



NicheMapR – a general system for mechanistic niche modelling



Ecography 40: 664–674, 2017

doi: 10.1111/ecog.02360

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Subject Editor: Brody Sandel. Editor-in-Chief: Miguel Araújo. Accepted 7 August 2016

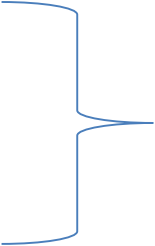
NicheMapR – an R package for biophysical modelling: the microclimate model

Michael R. Kearney and Warren P. Porter

M. R. Kearney (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.

Mechanistic Niche Models

Part I

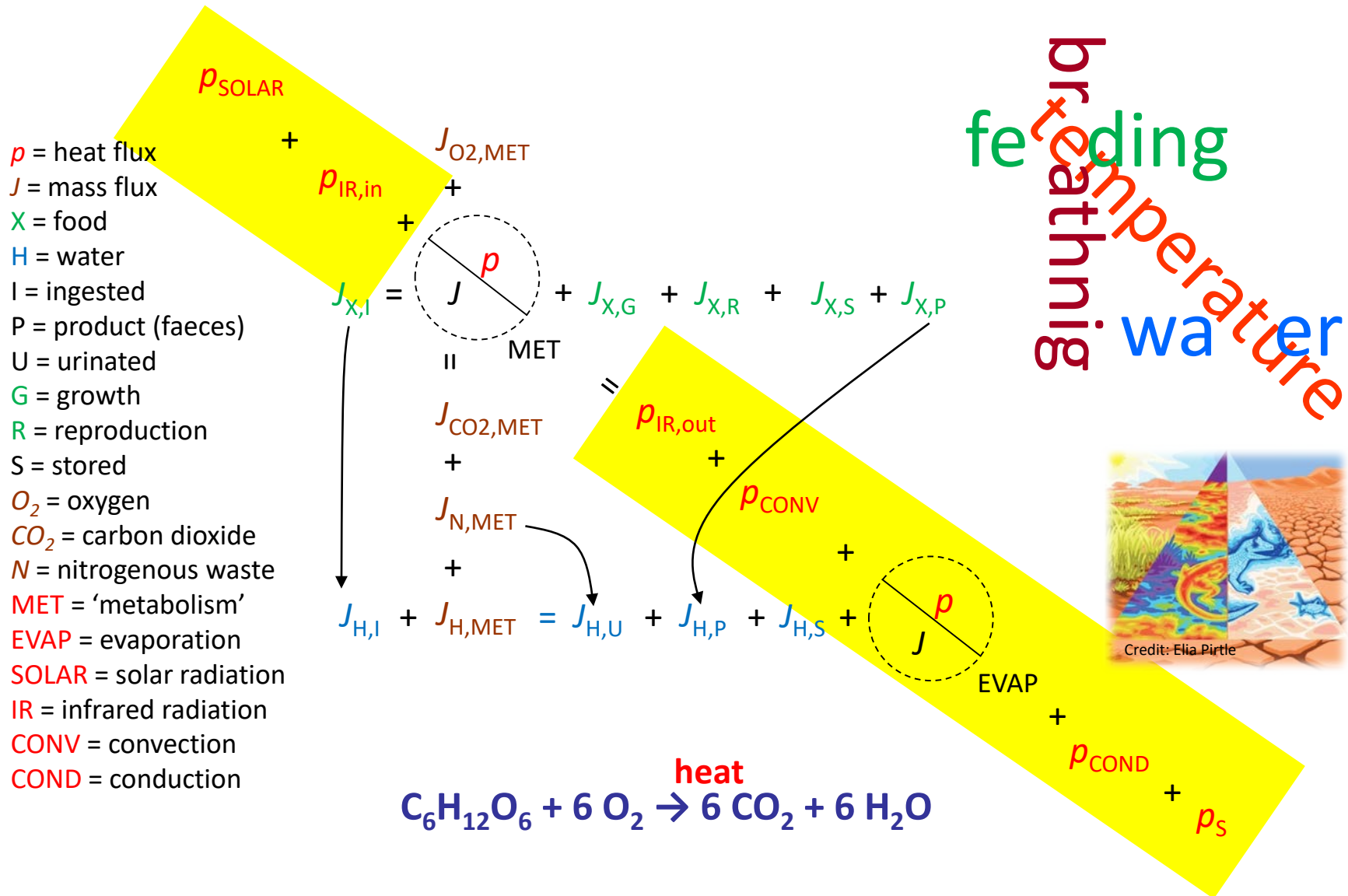
- What is a mechanistic niche model?
 - Thermodynamic basis to the niche
 - The importance of temperature
 - Heat budgets
 - Microclimates
 - Water budgets
 - Play with NicheMapR
- Biophysical Ecology
- 

Part II

- Connecting to the Dynamic Energy Budget
- Play with NicheMapR
- Inferring climatic constraints
- Nutritional constraints

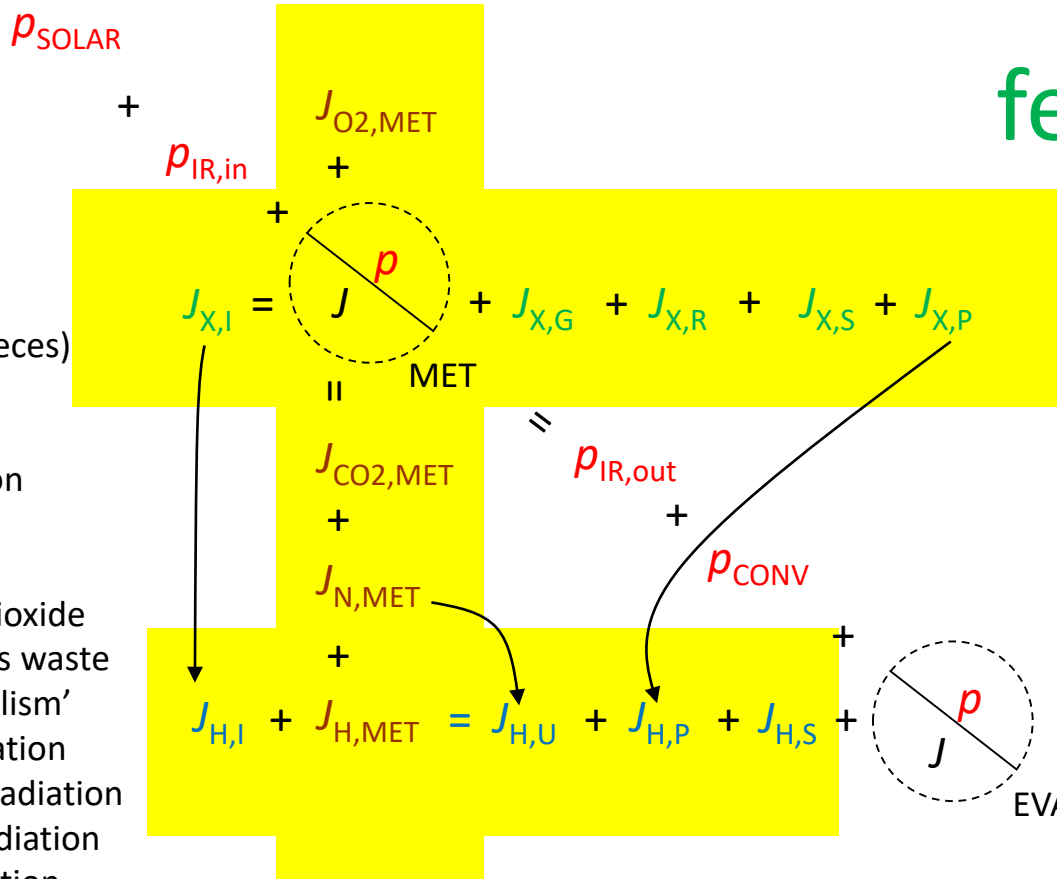
Thermodynamic basis to the niche

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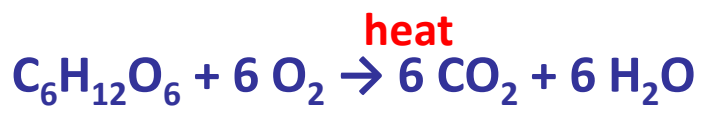
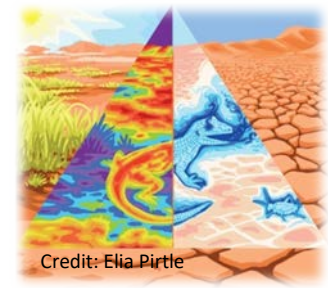


Thermodynamic basis to the niche

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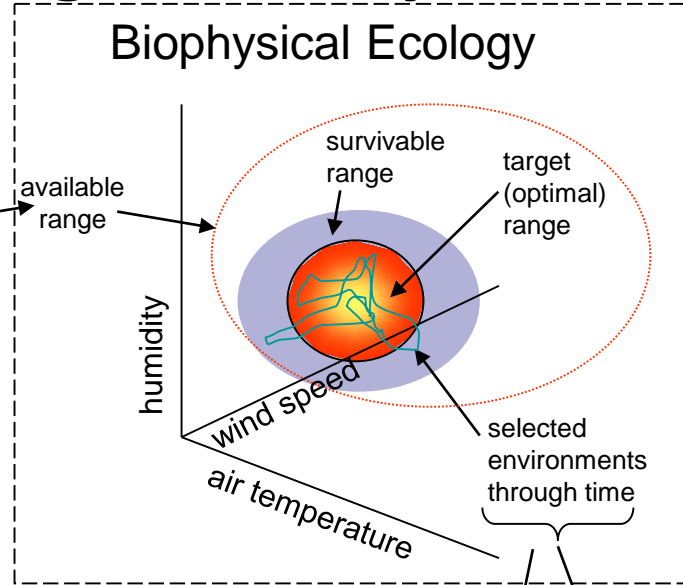
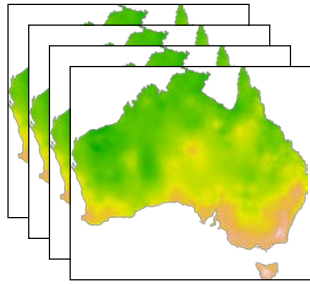


breathing temperature
 water

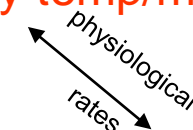


Connecting to the Dynamic Energy Budget

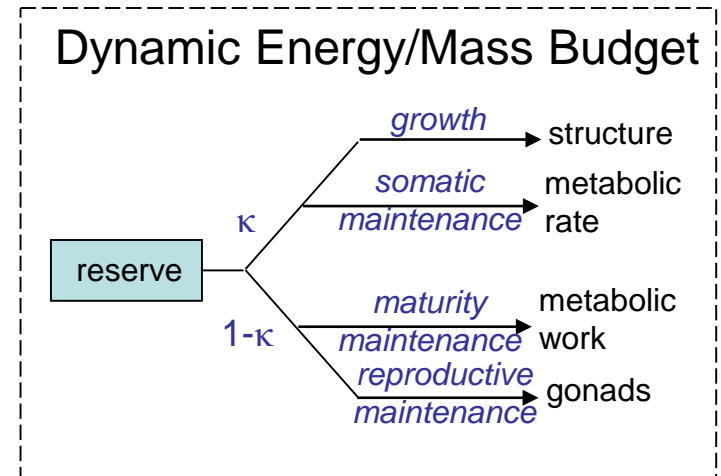
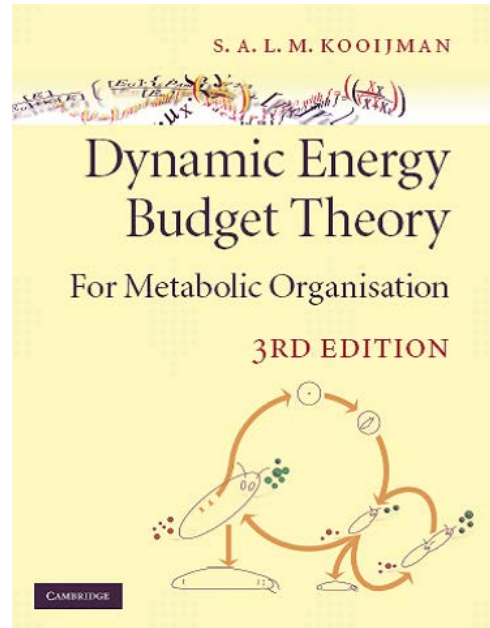
Environmental Layers



body temp/metabolic rate



water balance



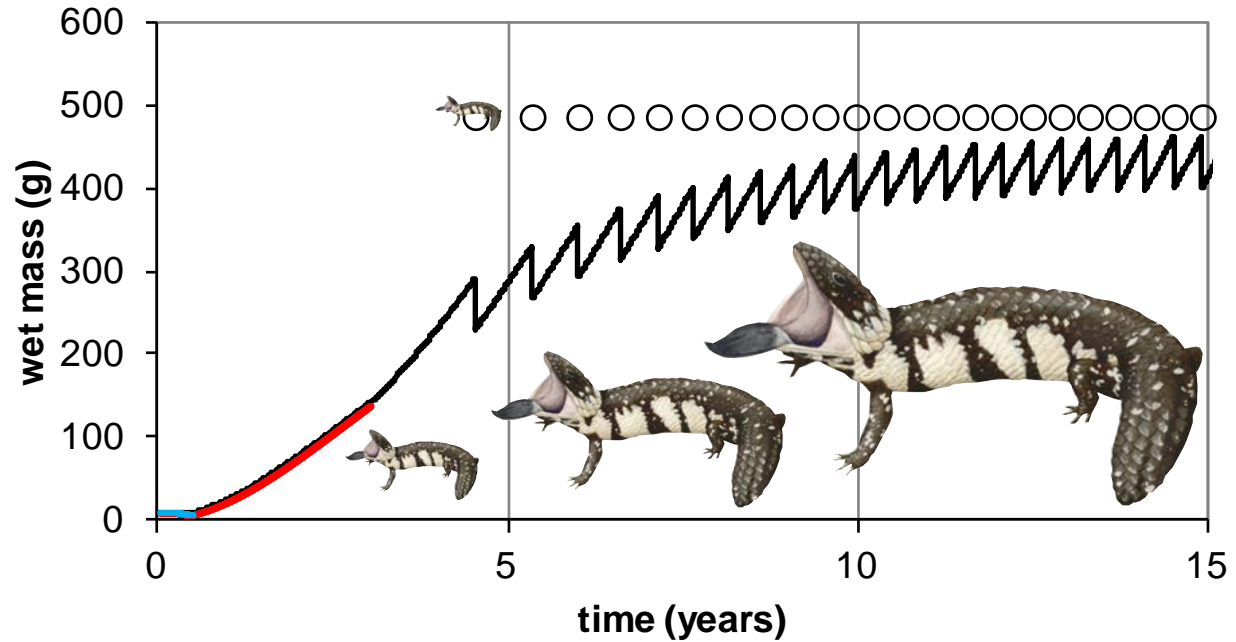
Connecting to the Dynamic Energy Budget

A year in the life of the Fence Lizard in Utah



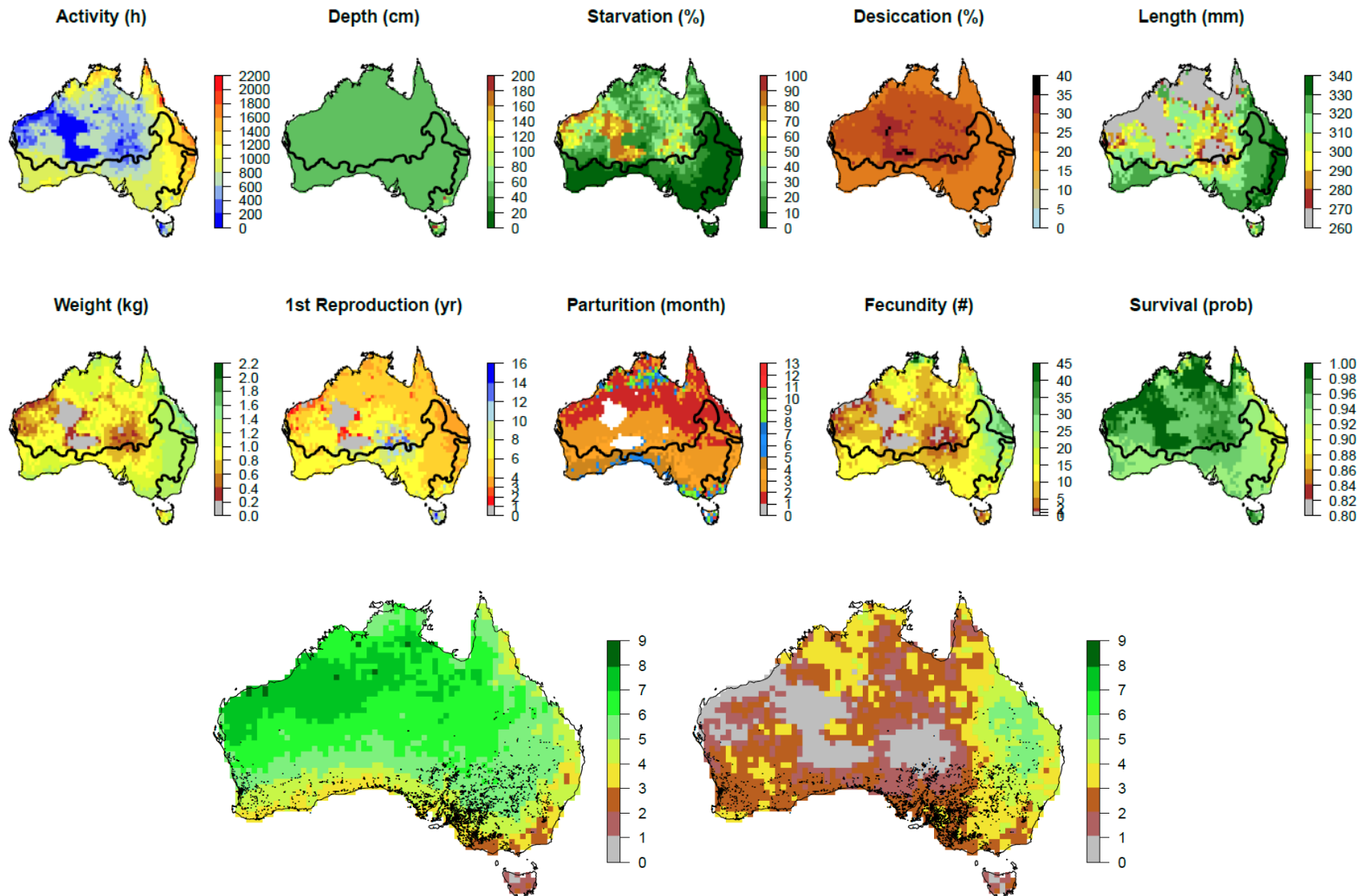
Inferring climatic constraints

growth (mass) and reproduction



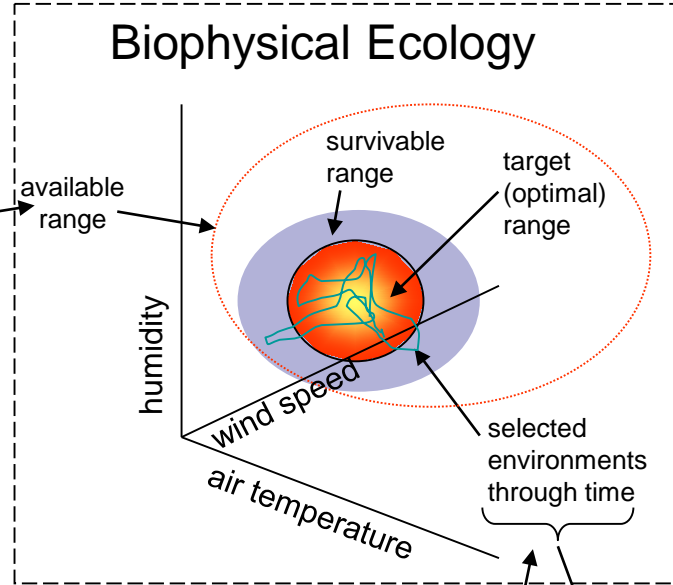
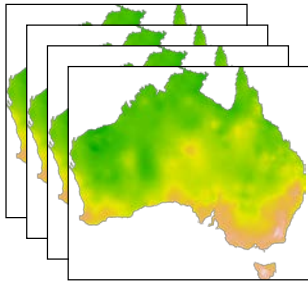
$$\begin{array}{c}
 \text{Food} \\
 \text{Structure} \\
 \text{Reserve} \\
 \text{Faeces}
 \end{array}
 \begin{pmatrix}
 n_{CX} & n_{CV} & n_{CE} & n_{CP} \\
 n_{HX} & n_{HV} & n_{HE} & n_{HP} \\
 n_{OX} & n_{OV} & n_{OE} & n_{OP} \\
 n_{NX} & n_{NV} & n_{NE} & n_{NP}
 \end{pmatrix}
 \begin{pmatrix}
 j_X \\
 j_V \\
 j_E + j_{ER} \\
 j_P
 \end{pmatrix}
 \begin{array}{l}
 \text{Food} \\
 \text{Structure} \\
 \text{Reserve} \\
 \text{Faeces}
 \end{array}
 =
 \begin{array}{c}
 \text{CO}_2 \text{ H}_2\text{O} \text{ O}_2 \text{ N waste} \\
 \begin{pmatrix}
 1 & 0 & 0 & n_{CN} \\
 0 & 2 & 0 & n_{HN} \\
 2 & 1 & 2 & n_{ON} \\
 0 & 0 & 0 & n_{NN}
 \end{pmatrix}
 \begin{pmatrix}
 j_C \\
 j_H \\
 j_O \\
 j_N
 \end{pmatrix}
 \begin{array}{l}
 \text{CO}_2 \\
 \text{H}_2\text{O} \\
 \text{O}_2 \\
 \text{N waste}
 \end{array}
 \end{array}$$

Inferring climatic constraints



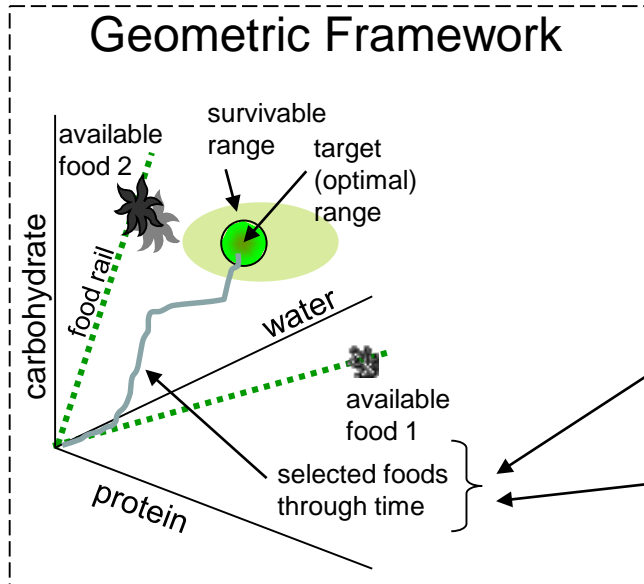
Nutritional constraints

Environmental Layers



Kearney and Porter TREE 2006

Kearney et al. PTRS 2010

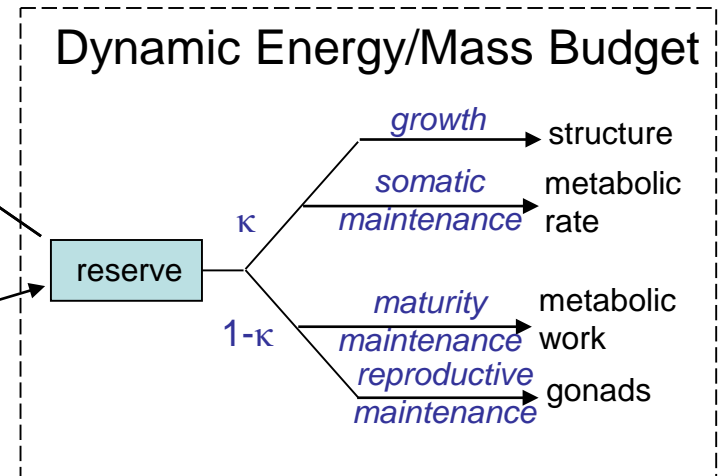


body temp/metabolic rate

physiological rates

water balance

food ingested



Nutritional constraints

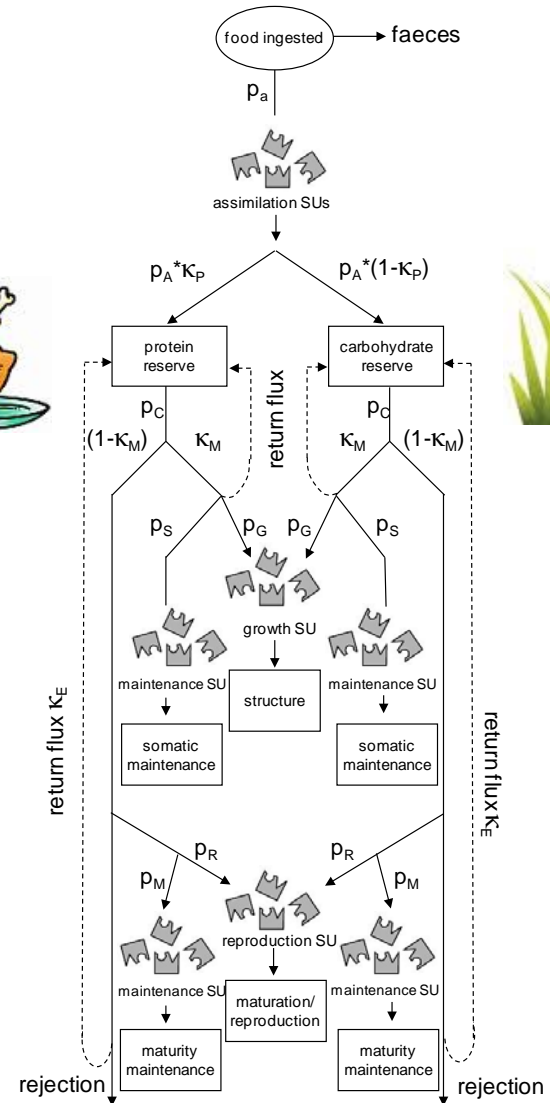
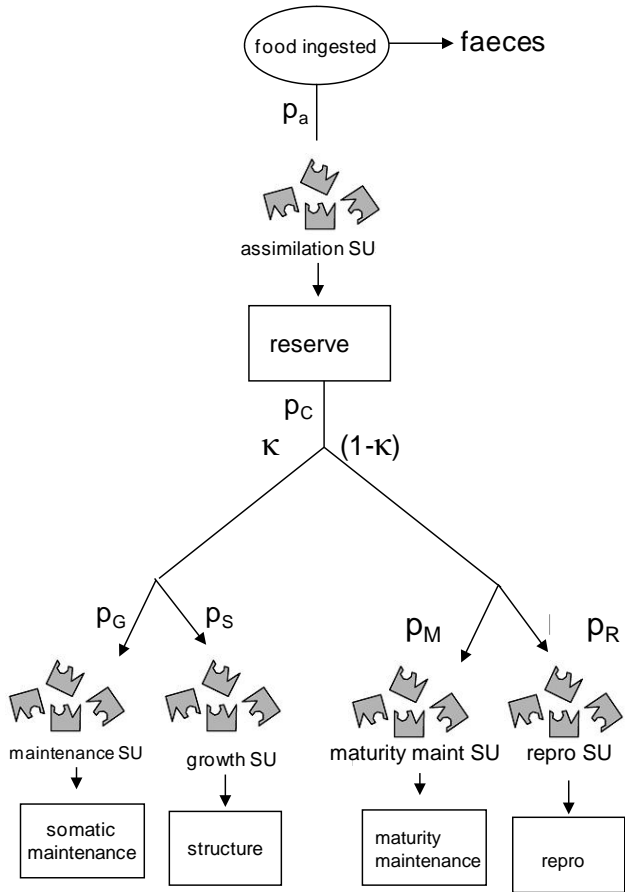
iso221

$$\begin{pmatrix} n_{CX} & n_{CV} & n_{CE} & n_{CP} \\ n_{HX} & n_{HV} & n_{HE} & n_{HP} \\ n_{OX} & n_{OV} & n_{OE} & n_{OP} \\ n_{NX} & n_{NV} & n_{NE} & n_{NP} \end{pmatrix} \begin{pmatrix} \dot{J}_X \\ \dot{J}_V \\ \dot{J}_E + \dot{J}_{E_R} \\ \dot{J}_P \end{pmatrix} \begin{matrix} \text{Food} \\ \text{Structure} \\ \text{Reserve} \\ \text{Faeces} \end{matrix}$$

$$\begin{pmatrix} n_{CX} & n_{CY} & n_{CV} & n_{CE_1} & n_{CE_2} & n_{CP_X} & n_{CP_Y} \\ n_{HX} & n_{HY} & n_{HV} & n_{HE_1} & n_{HE_2} & n_{HP_X} & n_{HP_Y} \\ n_{OX} & n_{OY} & n_{OV} & n_{OE_1} & n_{OE_2} & n_{OP_X} & n_{OP_Y} \\ n_{NX} & n_{NY} & n_{NV} & n_{NE_1} & n_{NE_2} & n_{NP_X} & n_{NP_Y} \end{pmatrix} \begin{pmatrix} \dot{J}_X & \dot{J}_Y & \dot{J}_V & \dot{J}_{E_1} + \dot{J}_{E_{1R}} & \dot{J}_{E_2} + \dot{J}_{E_{2R}} & \dot{J}_{P_X} & \dot{J}_{P_Y} \end{pmatrix}^T$$

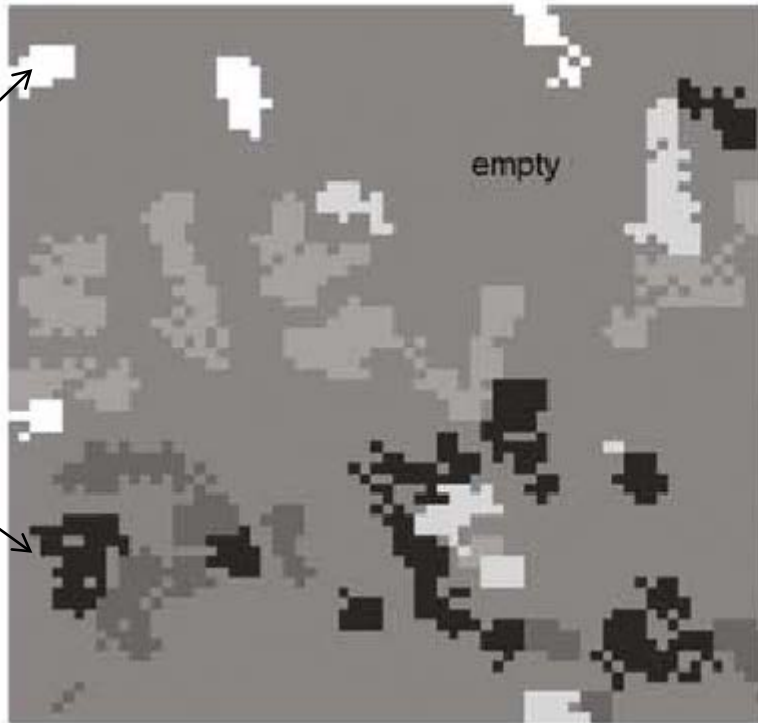
Nutritional constraints

iso221

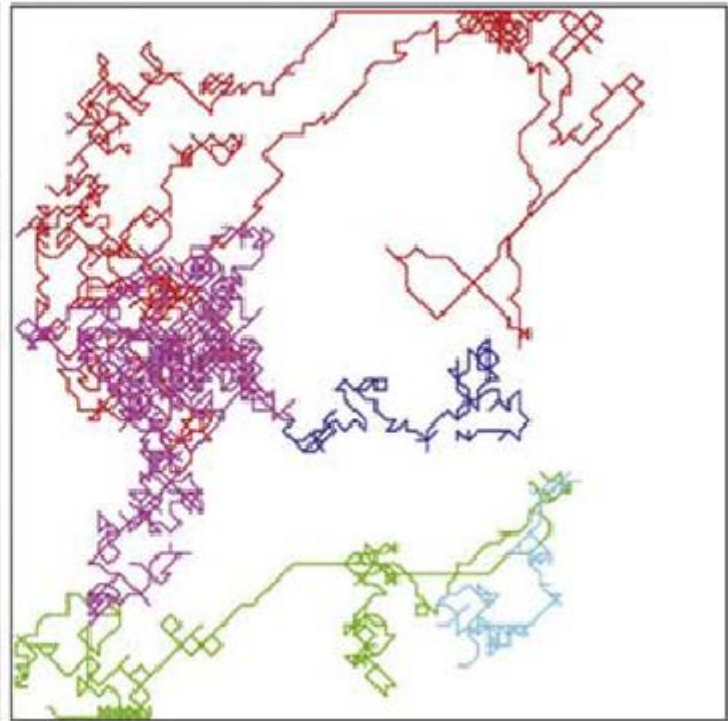


Nutritional constraints

Nutritional Landscape

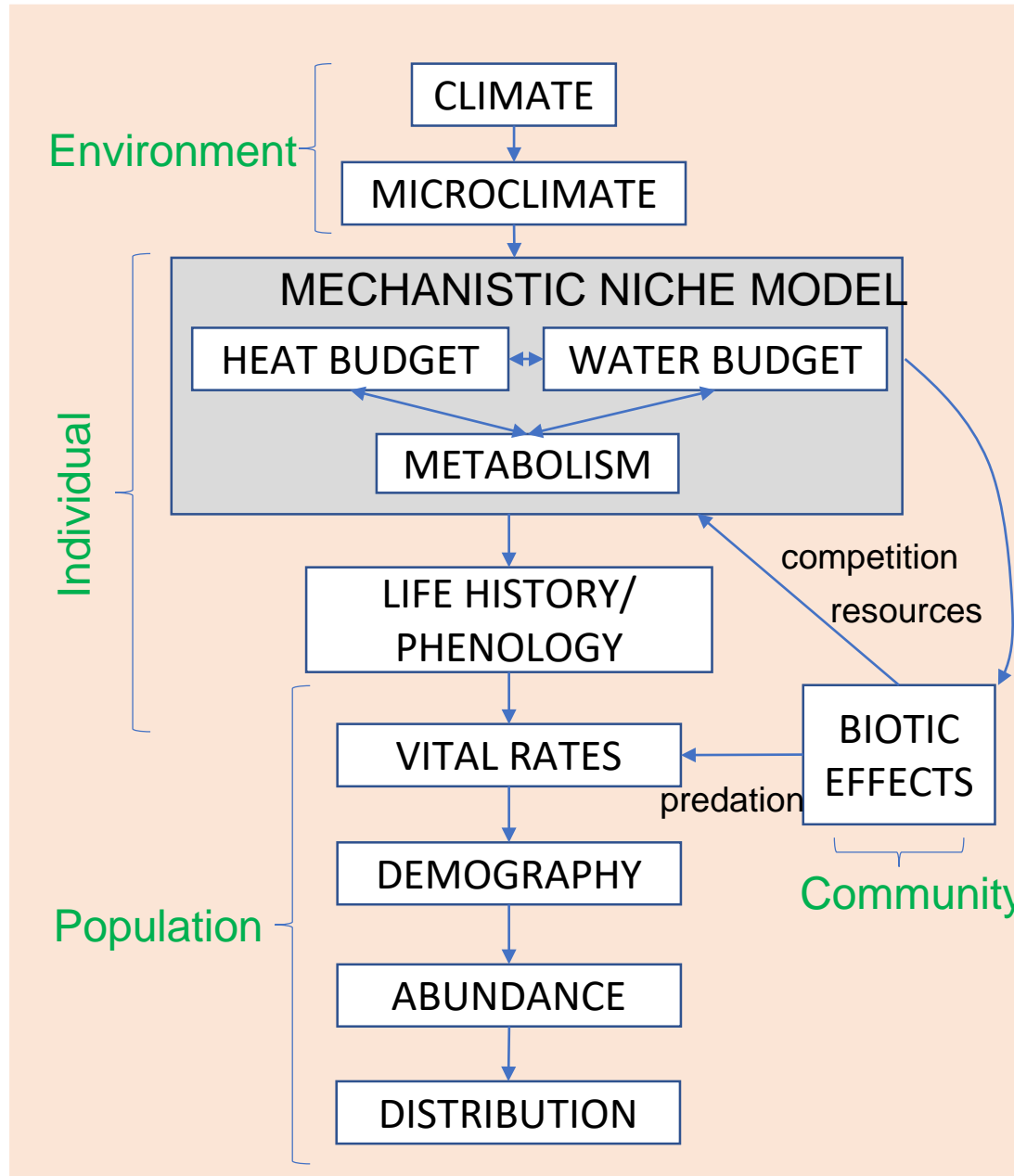
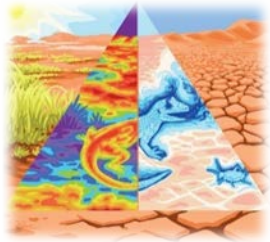


Agent Behaviour



- Preference behaviour/targets will change with ontogeny

Mechanistic Niche Models



feeding
temperature
water
breathing