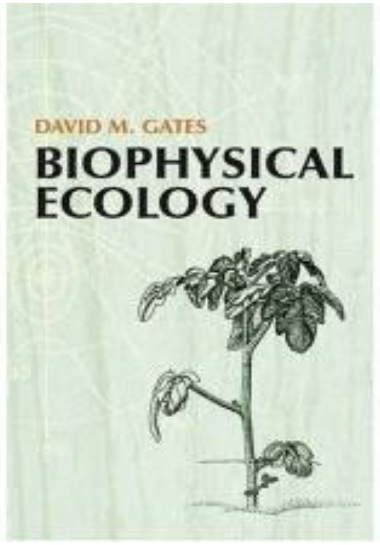
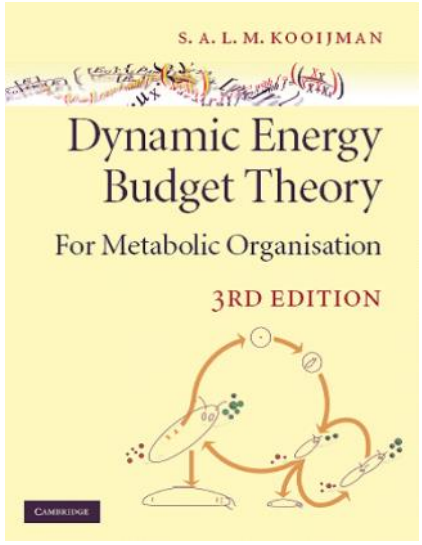
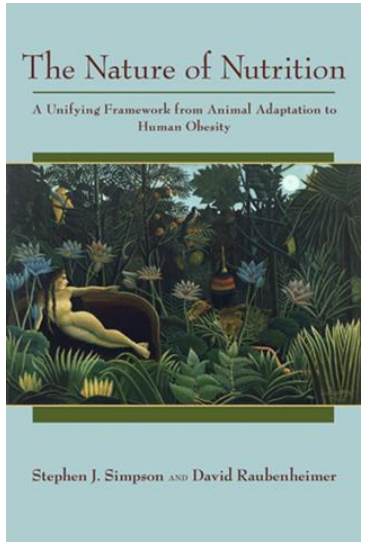




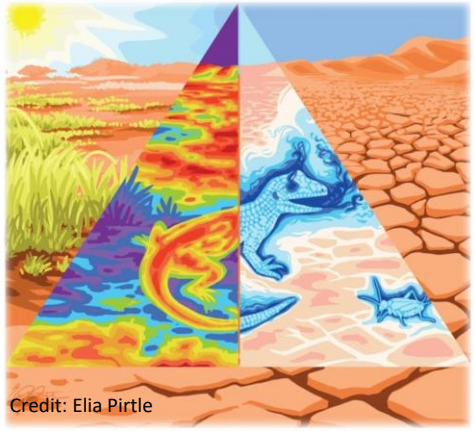


DEB, the Ecological Niche and Functional Traits

Michael Kearney

School of BioSciences

THE UNIVERSITY OF MELBOURNE


Credit: Elia Pirtle

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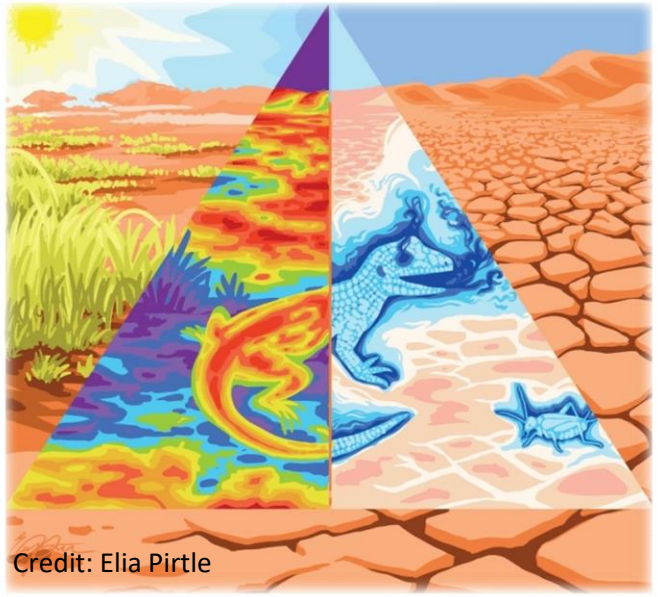
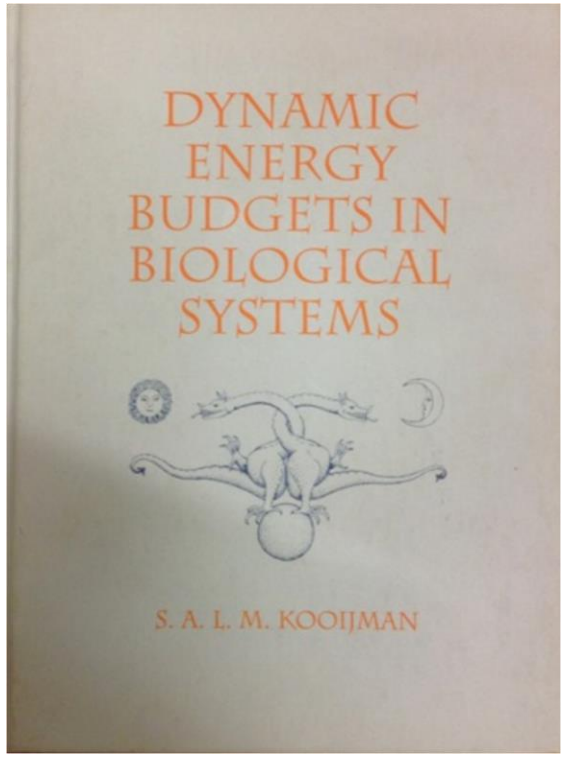
Topics

- What is the ecological niche?
- How can we define the niche thermodynamically?
- Biophysical ecology
- Connecting to DEB theory
- Functional traits and mechanistic niche models
- Sneak peak at a new R Shiny app

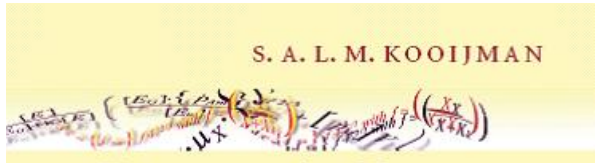


Credit: Elia Pirtle

Individuals are special



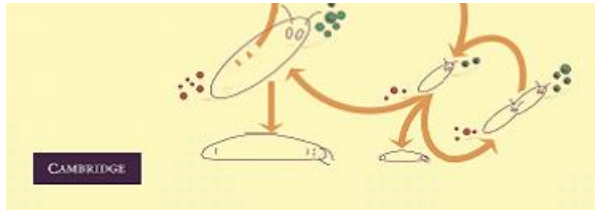
1993



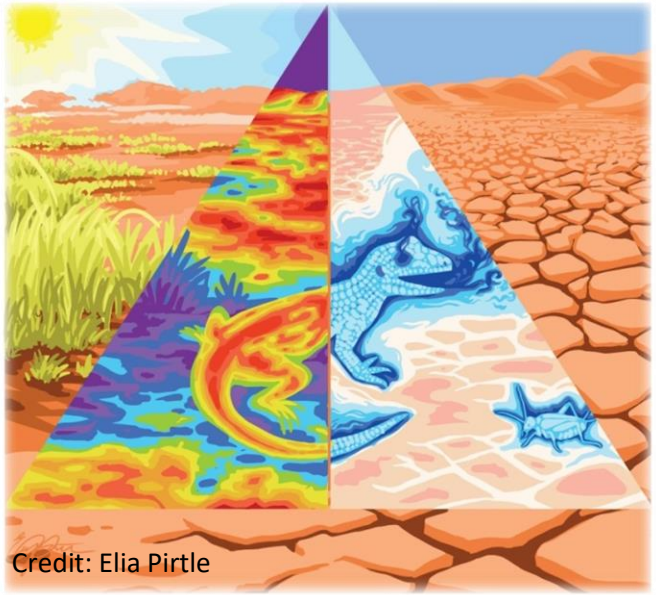
Cover figure:

Sitting on the stone of wisdom, the mediaeval dragons symbolize the message that, when reaching out for both the micro- and the macro-world, the wise focus is on individuals.

2000

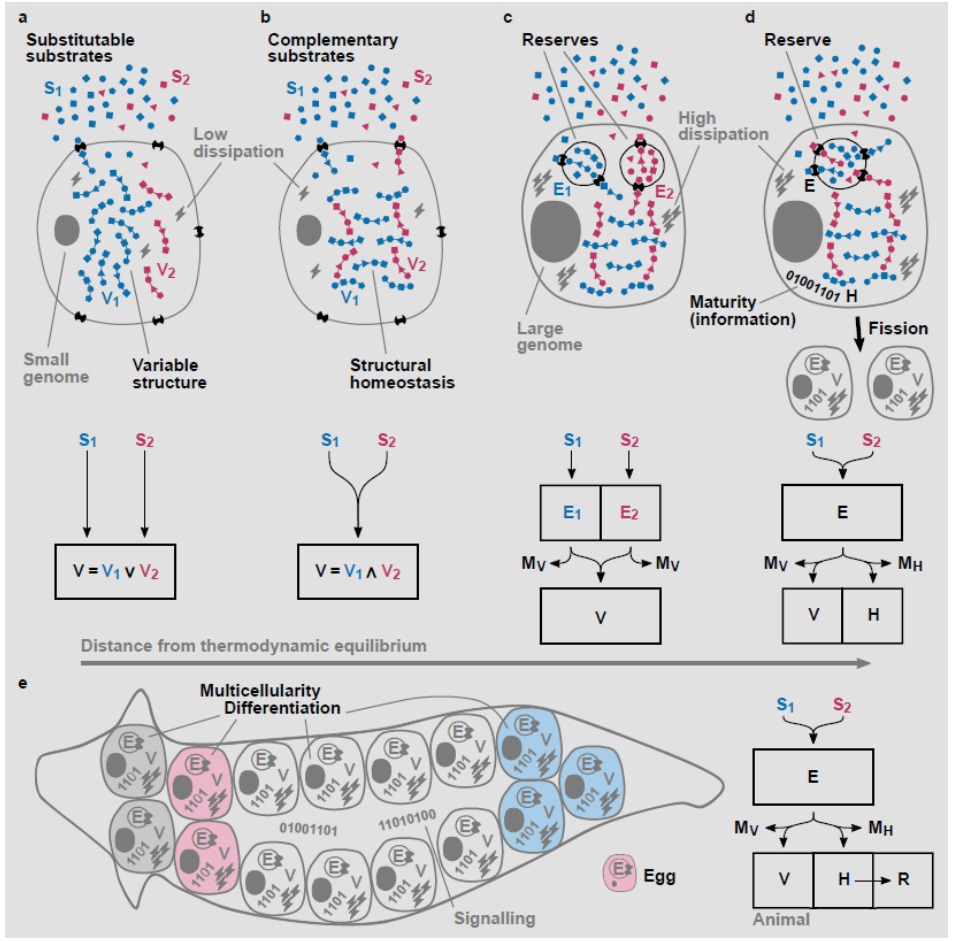


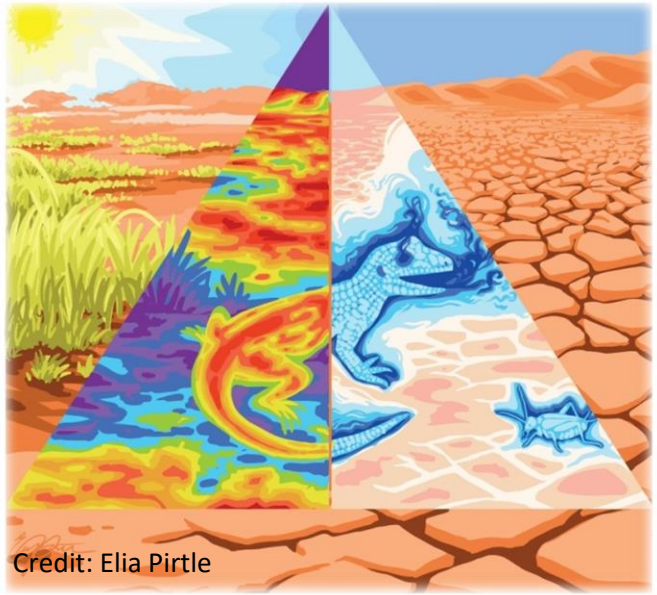
2010



Credit: Elia Pirtle

Individuals are special




Credit: Elia Pirtle

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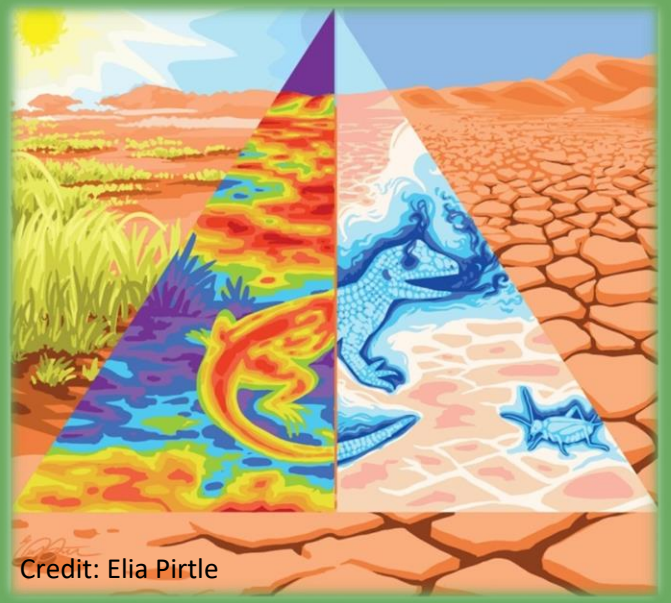


Credit: Elia Pirtle

1.

What is the ecological niche?

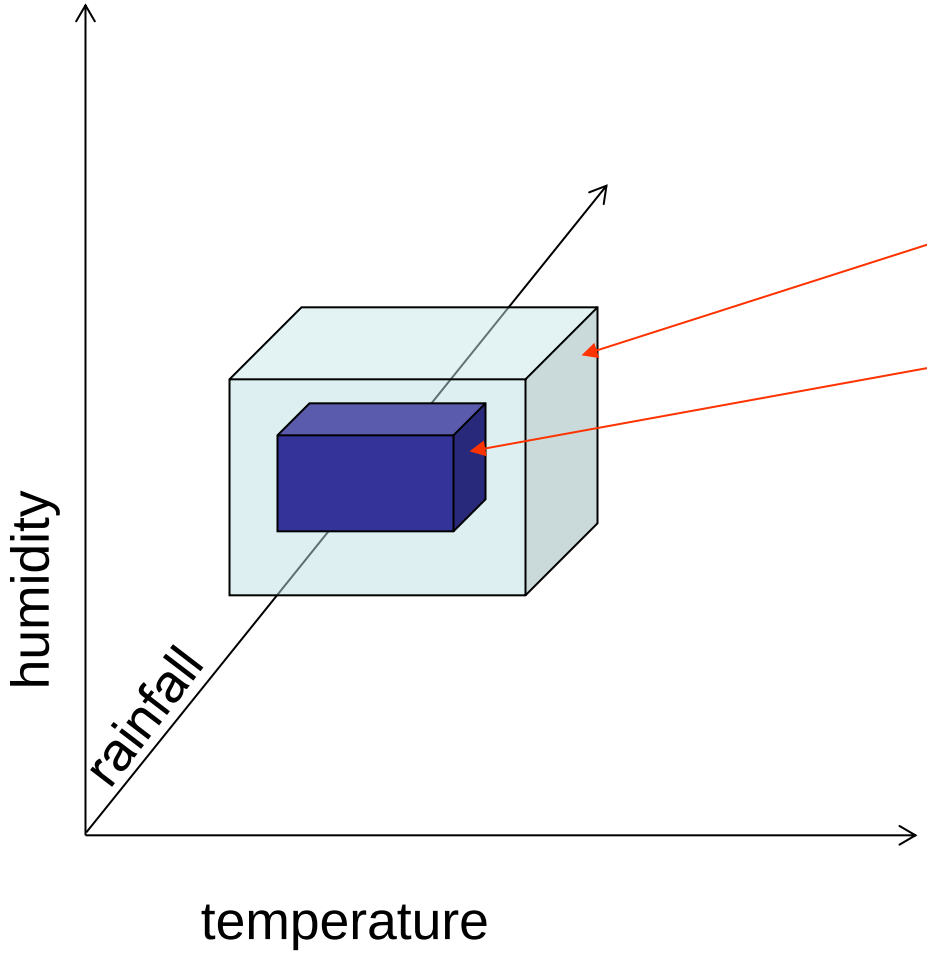
Hutchinsonian niche concept

Modelling the Hutchinsonian niche

Hutchinsonian niche

G. Evelyn Hutchinson

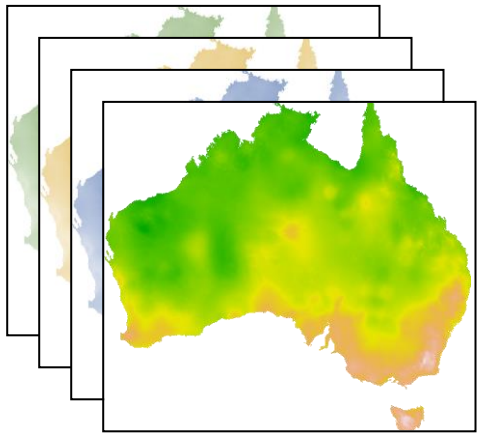
Robert H. MacArthur



fundamental niche

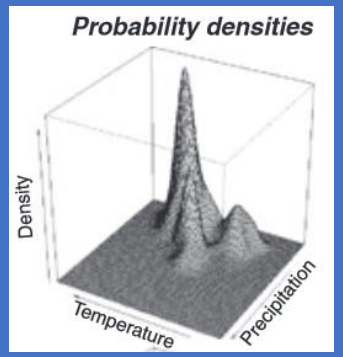
realized niche

Ecological Niche Modelling

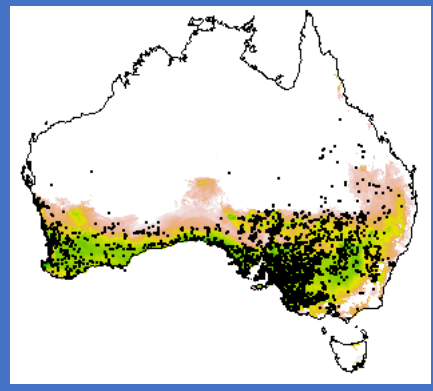


Correlative Model (process implicit)

Maxent model



probability of occurrence



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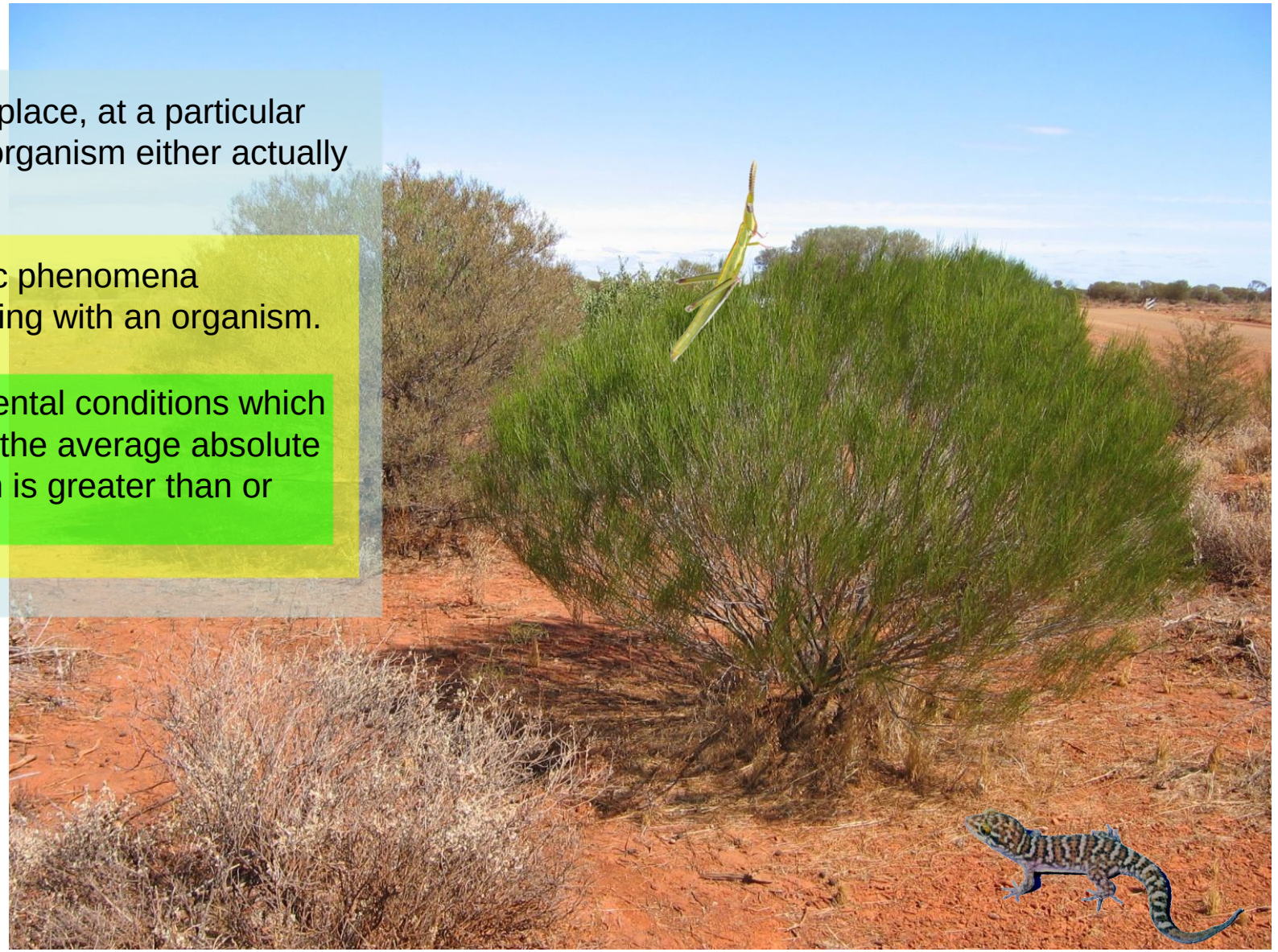
Habitat vs. environment vs. niche

Habitat: a description of a physical place, at a particular scale of space and time, where an organism either actually or potentially lives.

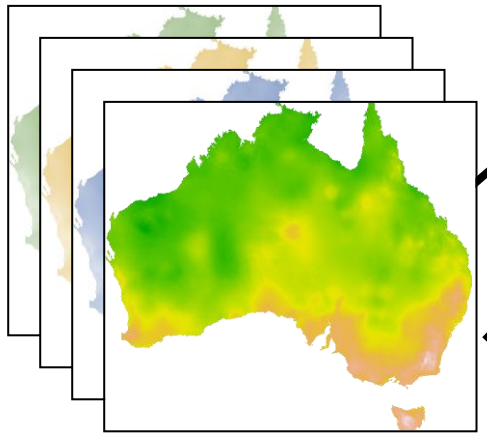
Environment: the biotic and abiotic phenomena surrounding and potentially interacting with an organism.

Niche: a subset of those environmental conditions which affect a particular organism, where the average absolute fitness of individuals in a population is greater than or equal to one.



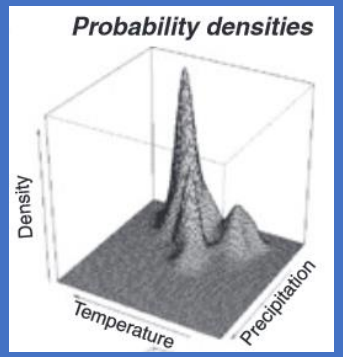
Kearney, M. 2006. Habitat, environment and niche: what are we modelling? — Oikos 115: 186-191.

Ecological Niche Modelling

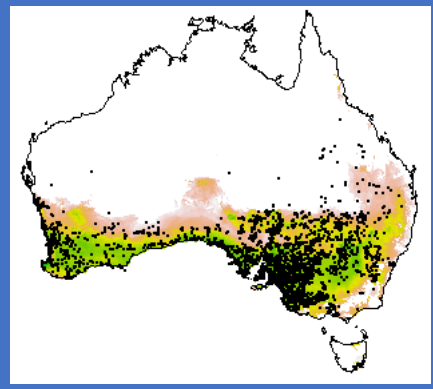


Correlative Model (process <u>implicit</u>)

Maxent model

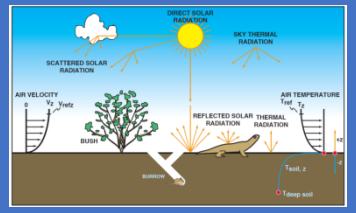


probability of occurrence

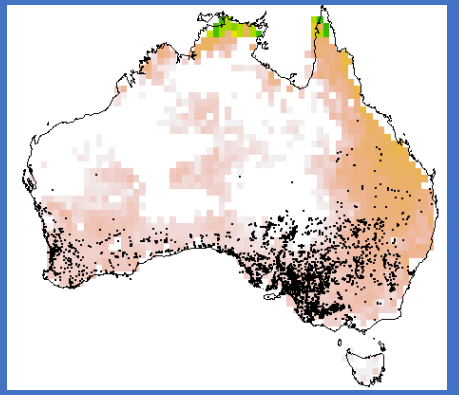


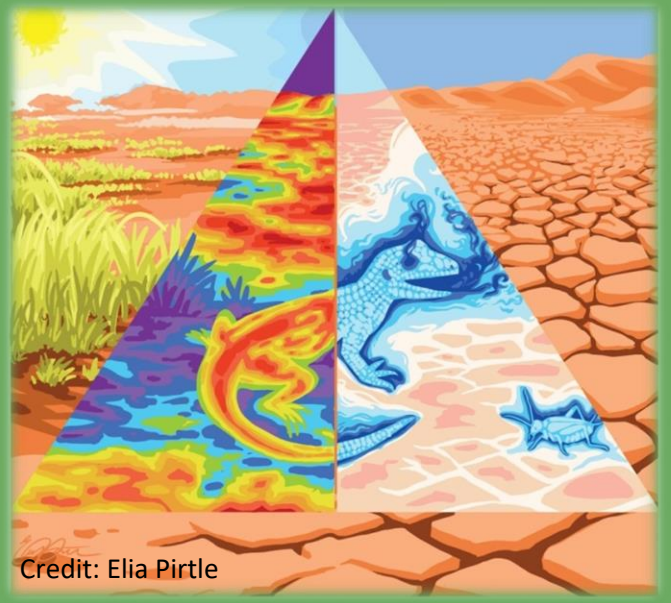
Mechanistic Model (process <u>explicit</u>)

Thermodynamic Niche Model



potential reproduction





Credit: Elia Pirtle

2. Thermodynamic niche?

Organisms as thermodynamic systems

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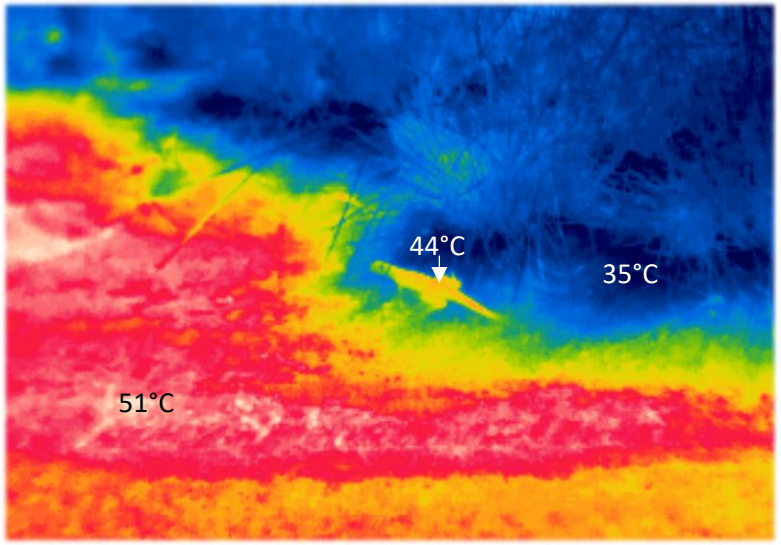
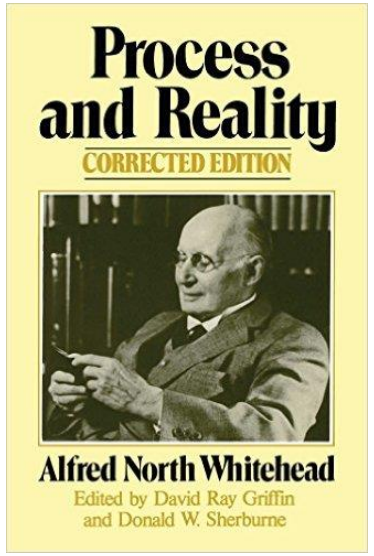
Thermodynamic basis to the niche

Military Dragon, *Ctenophorus isolepis*





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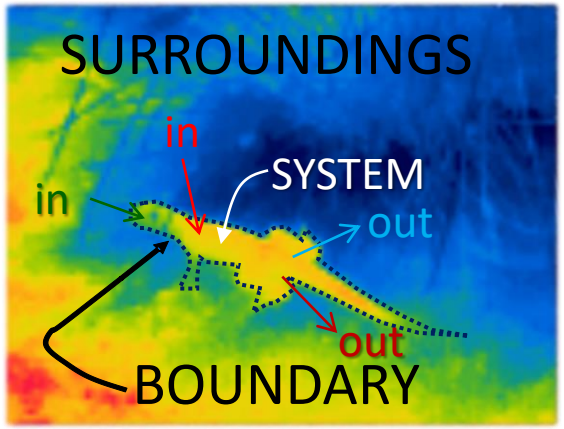
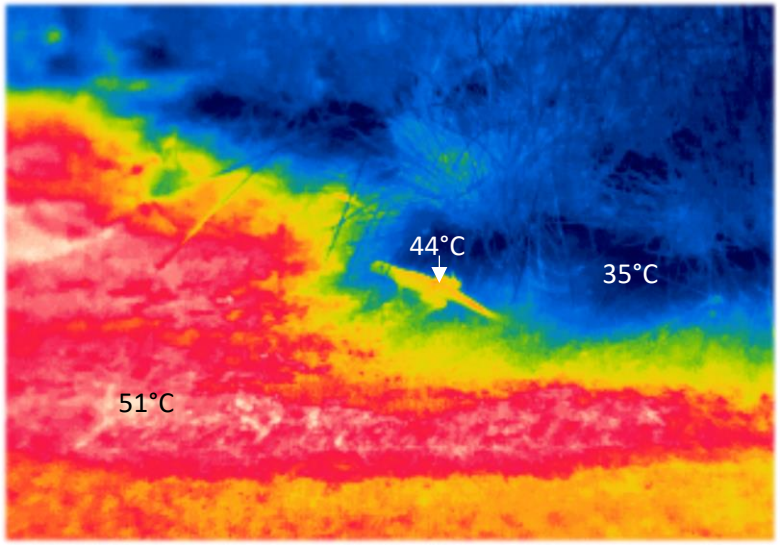
Thermodynamic basis to the niche

energy in =
energy out + energy stored

mass in =
mass out + mass stored





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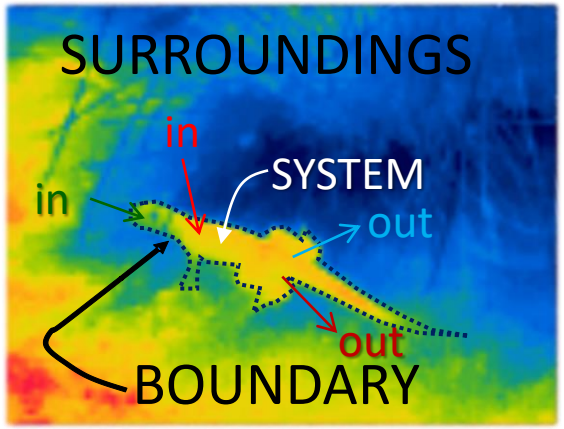
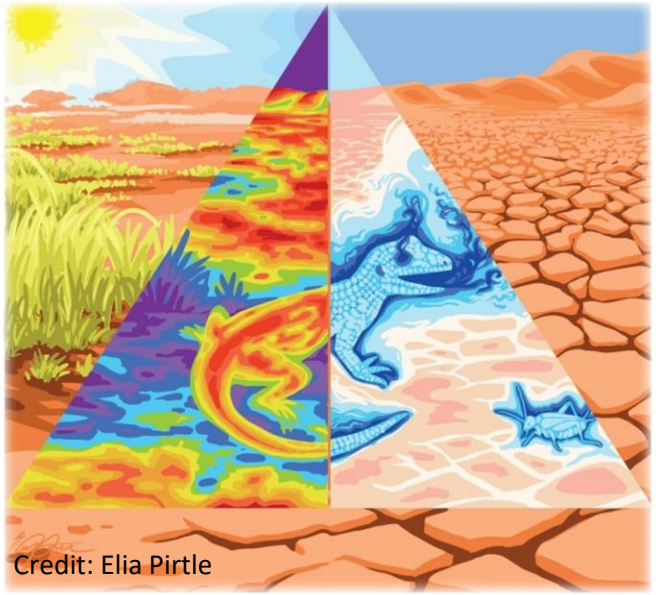
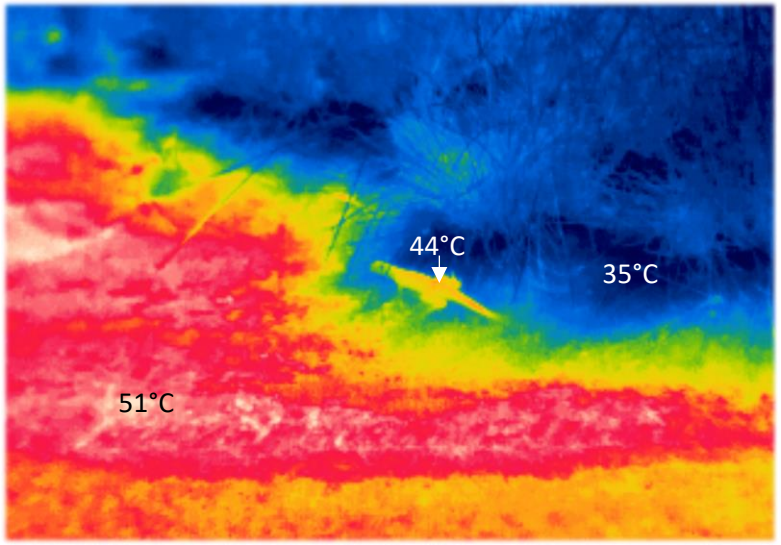



Credit: Elia Pirtle



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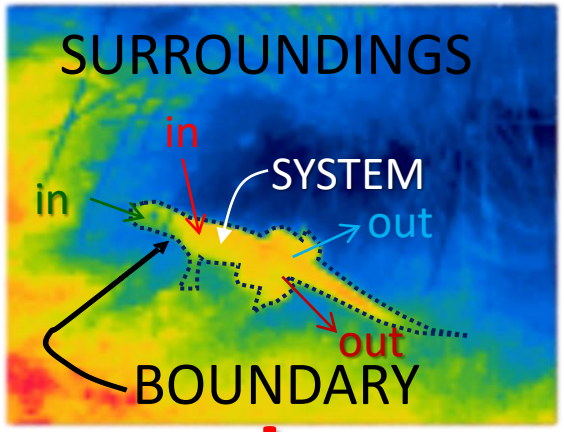
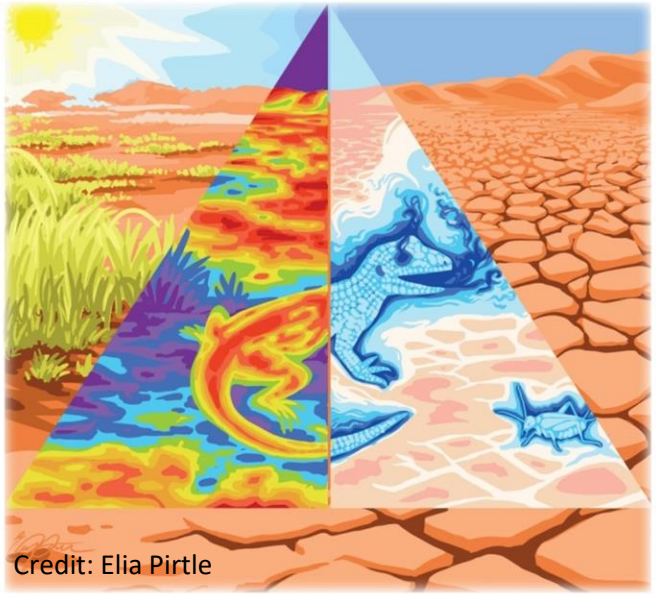
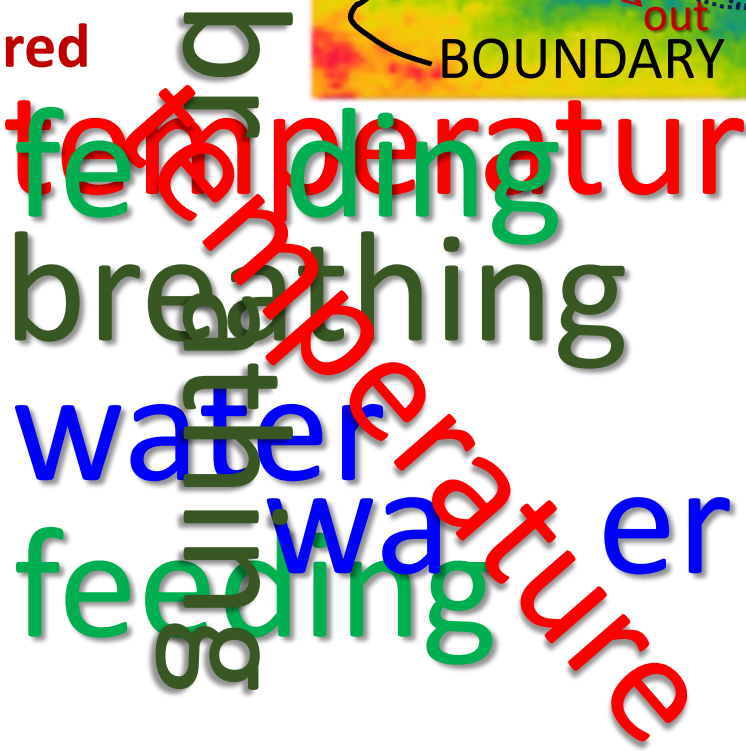



Credit: Elia Pirtle



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

$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{J\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P} = p_{IR,out} + J_{CO2,MET} + J_{N,MET}$$

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

Credit: Elia Pirtle

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)

Thermodynamic basis to the niche

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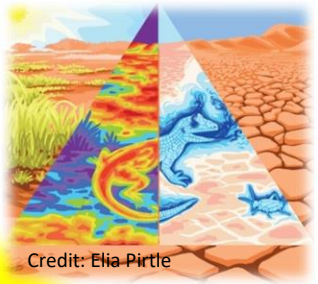
$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \left(\frac{p}{J}\right)_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P}$$

$$= p_{IR,out} + J_{CO2,MET} + p_{CONV} + J_{N,MET} + \left(\frac{p}{J}\right)_{EVAP} + p_{COND}$$

$$J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S}$$

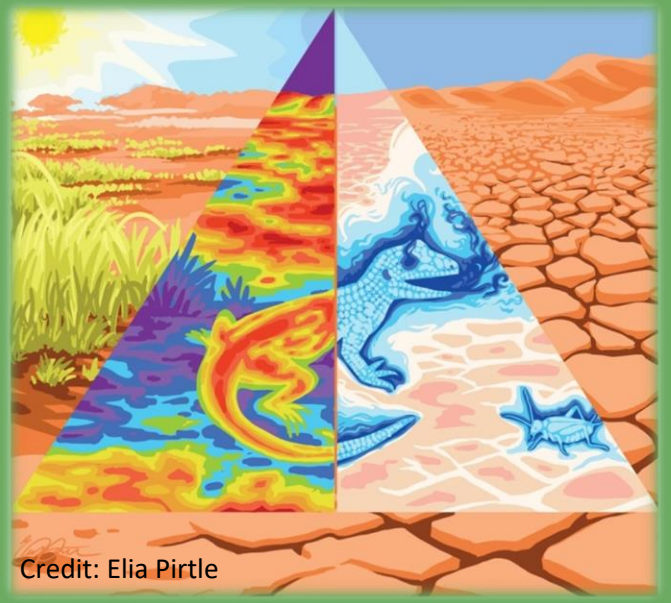

Credit: Elia Pirtle

breathing temperature feeding water

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)



Credit: Elia Pirtle

2. Biophysical Ecology

Computing a heat budget

Computing a water budget

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Biophysical Ecology

THERMODYNAMIC EQUILIBRIA OF ANIMALS WITH ENVIRONMENT[1]

WARREN P. PORTER[2] 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

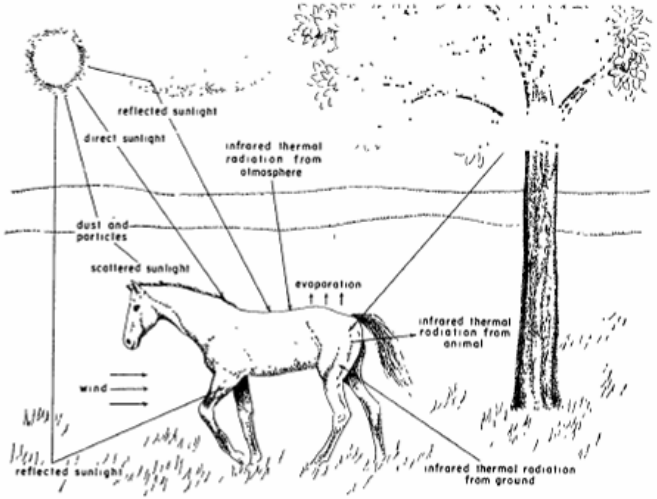
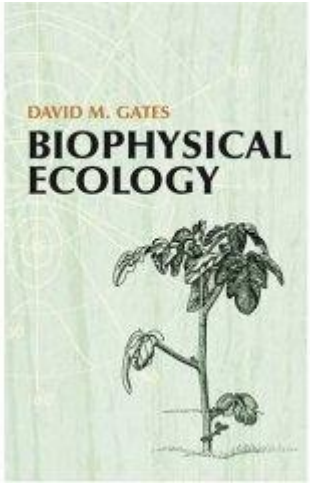


FIG. 1. Streams of energy between an animal and the environment.



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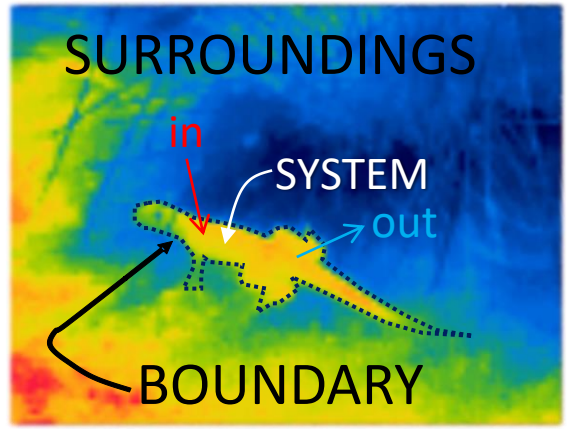
Computing a heat budget



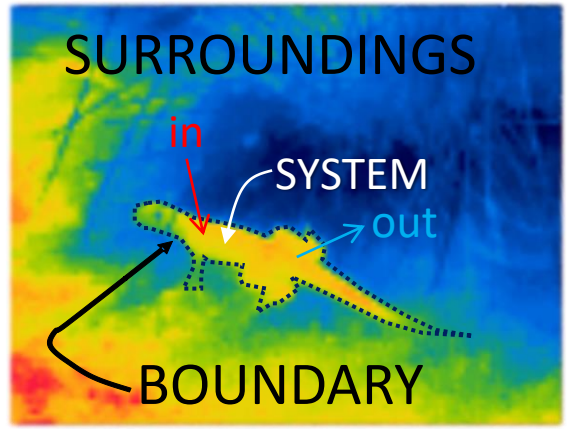
energy in = energy out

(Heat) Energy Balance of a Lizard

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

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

Computing a heat budget



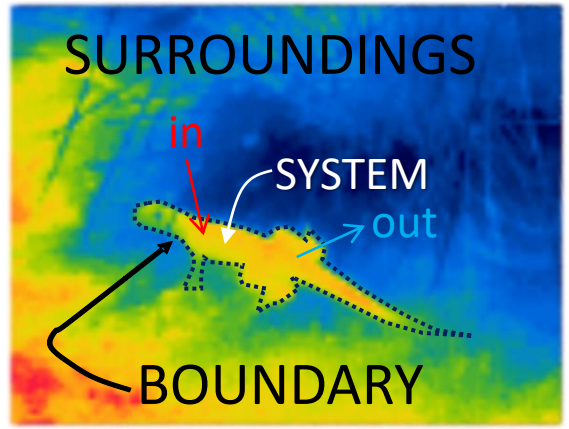
energy in = energy out

(Heat) Energy Balance of a Lizard

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

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

Computing a heat budget



energy in = energy out

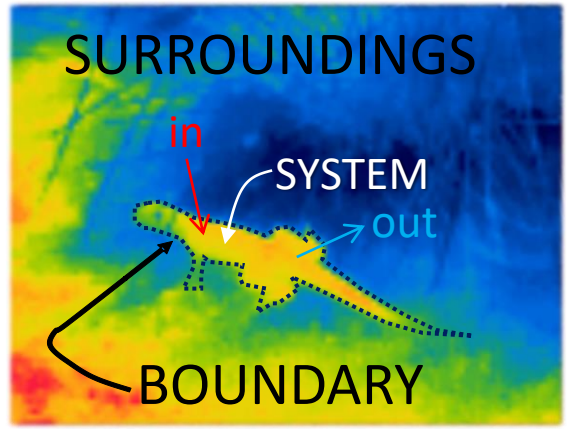
(Heat) Energy Balance of a Lizard

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

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

$$\overbrace{A\alpha Q_{sol} + AQ_{IR}}^{\text{radiation gain}} = \underbrace{A\varepsilon\sigma[T_b + 273.15]^4}_{\text{infra-red radiation lost}} + \overbrace{Ah_c\,[T_b - T_a]}^{\text{convection}}$$

Computing a heat budget



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(Heat) Energy Balance of a Lizard

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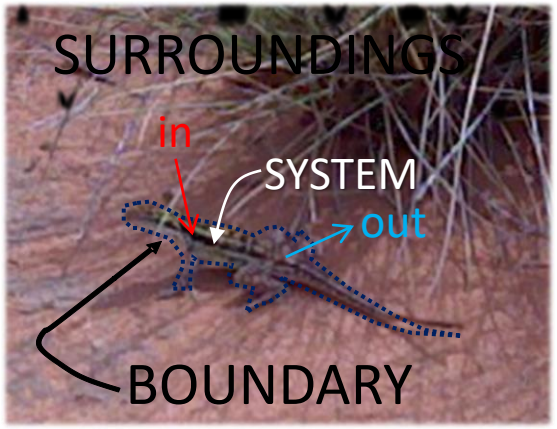
Computing a heat budget



energy in = energy out

(Heat) Energy Balance of a Lizard

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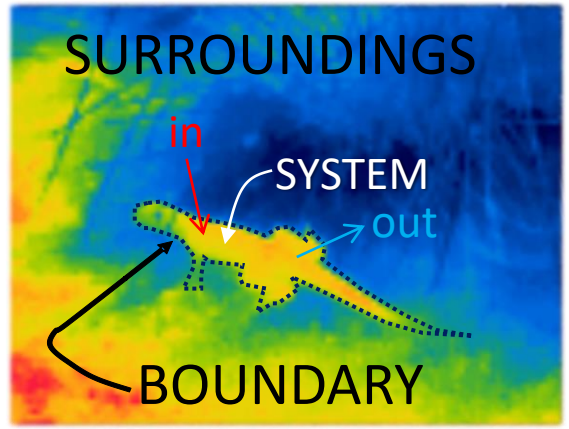
Infra-red (lost) + Convection (gained/lost)

$$\underbrace{\alpha Q_{sol} + Q_{IR}}_{\text{radiation gain}} - \underbrace{\varepsilon\sigma[T_b + 273.15]^4}_{\text{infra-red radiation lost}} - \underbrace{h_c\,[T_b - T_a]}_{\text{convection}} = 0$$

Computing a heat budget



energy in = energy out

(Heat) Energy Balance of a Lizard

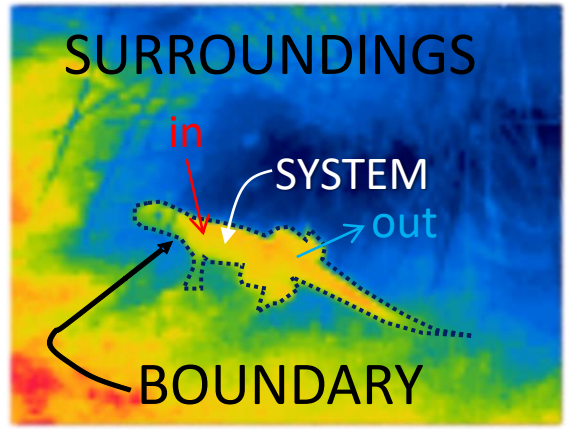
Solar (gained) + Infra-red (gained) =

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

radiation gain — convection

$$Q_a - \underbrace{\varepsilon\sigma[T_b + 273.15]^4}_{\text{infra-red radiation lost}} - h_c\,[T_b - T_a] = 0$$

Computing a heat budget



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

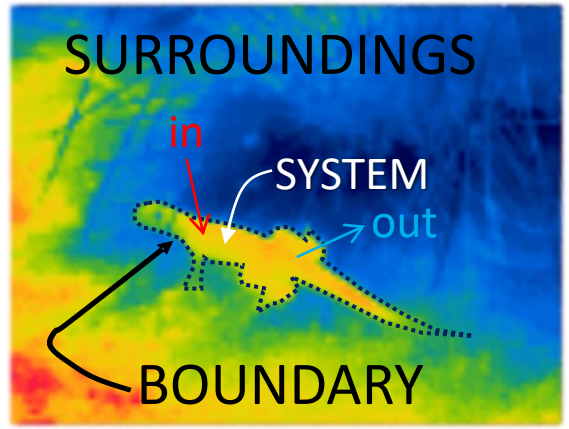
Infra-red (lost) + Convection (gained/lost)

$$\underbrace{Q_a}_{\text{radiation gain}} - \underbrace{\varepsilon\sigma[T_b + 273.15]^4}_{\text{infra-red radiation lost}} - \overbrace{3.49\frac{V^{0.5}}{D^{0.5}}[T_b - T_a]}^{\text{convection}} = 0$$

$$h_c = 3.49\frac{V^{0.5}}{D^{0.5}}$$

wind speed V, organism size D

Computing a heat budget



energy in = energy out

body temperature T_b (°C)
air temperature T_a (°C)
radiation absorbed Q_a (W/m^2)
wind speed V (m/s)
organism size D (m)
emissivity ε (-)
Stefan-Boltzmann constant σ(W/m^2·K^4)

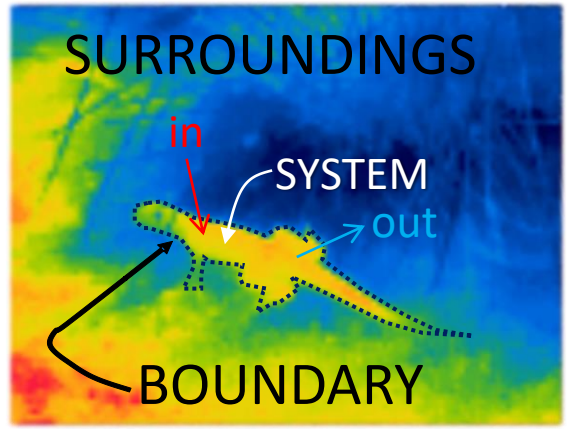
(Heat) Energy Balance of a Lizard

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

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

$$Q_a - \varepsilon\sigma[T_b + 273.15]^4 - 3.49\frac{V^{0.5}}{D^{0.5}}[T_b - T_a] = 0$$

Computing a heat budget



What would the body temperature be if …?

Diameter = 0.015 m

Wind speed = 2.0 m/s

Air temperature = 20 ºC

Radiation = 700 W/m2

T_b = 26 ºC

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

$$Q_a - \varepsilon\sigma[T_b + 273.15]^4 - 3.49\frac{V^{0.5}}{D^{0.5}}[T_b - T_a] = 0$$

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

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

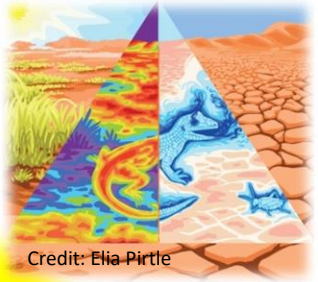
$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{p, J\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P}$$

$$= p_{IR,out} + J_{CO2,MET} + J_{N,MET}$$

$$+ p_{CONV} + \{p, J\}_{EVAP} + p_{COND}$$

$$J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S}$$

breathing feeding temperature water

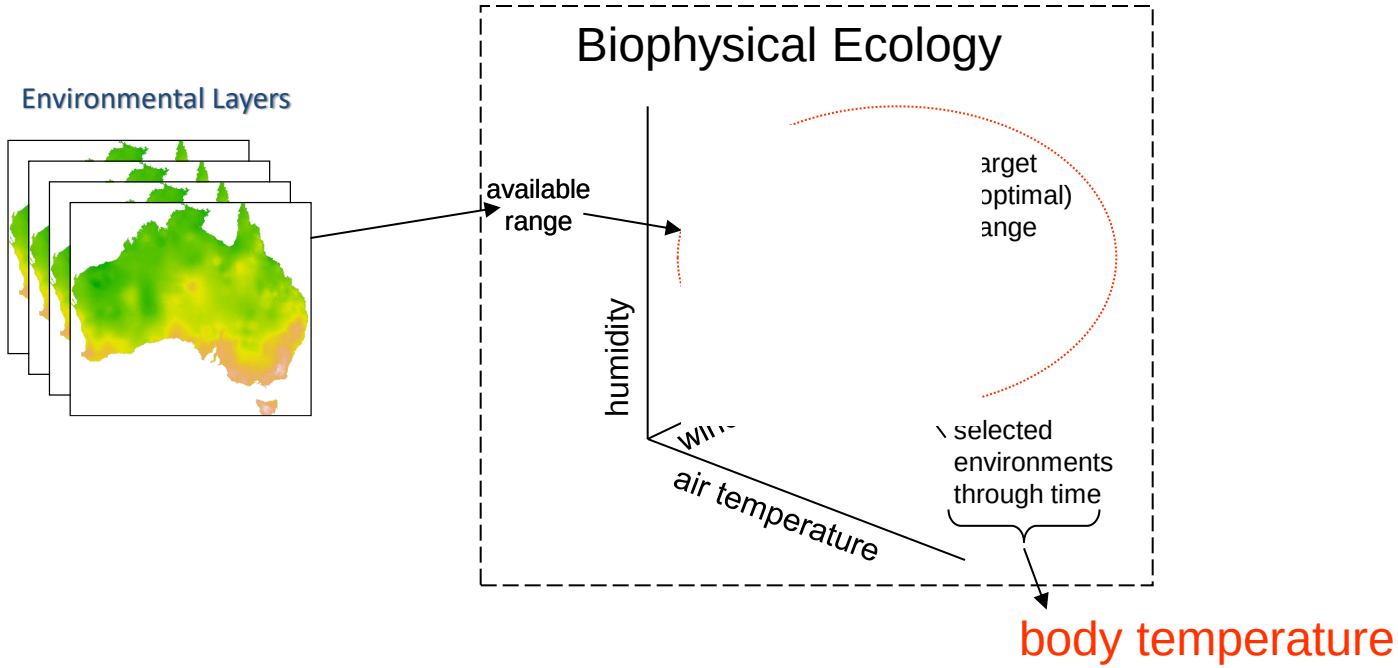

Credit: Elia Pirtle

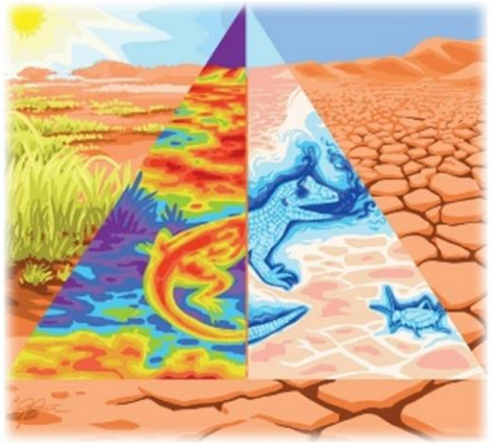
heat

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

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

Thermodynamic basis to the niche





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$$= p_{IR,out} + J_{CO2,MET} + J_{N,MET} + p_{CONV}$$

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

heat

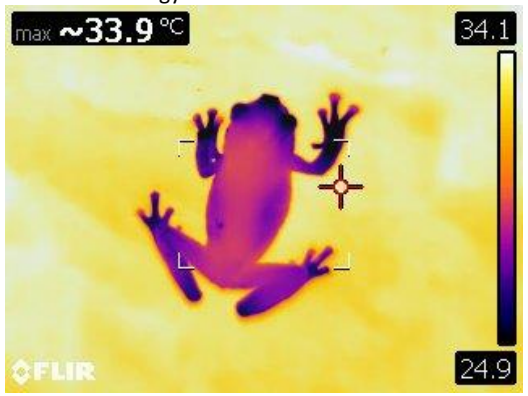
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$

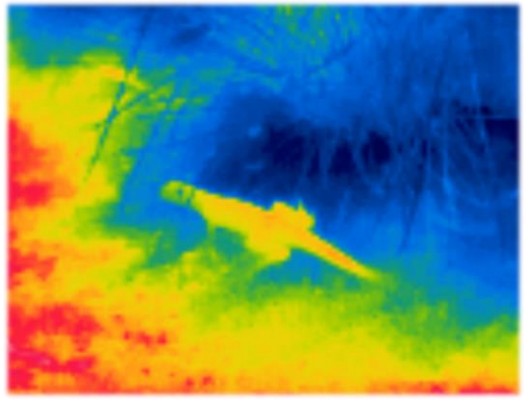
Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

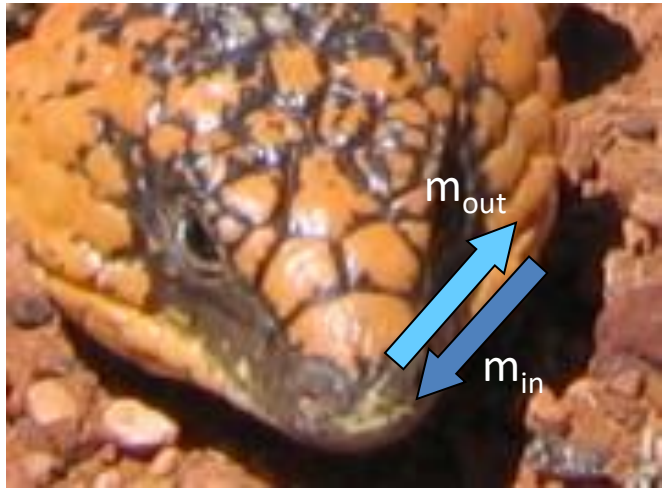
Credit: Elia Pirtle

Computing a water budget

Greer 1989 Biology and Evolution of Australian Lizards







area wet, m^2

latent heat of vaporisation,

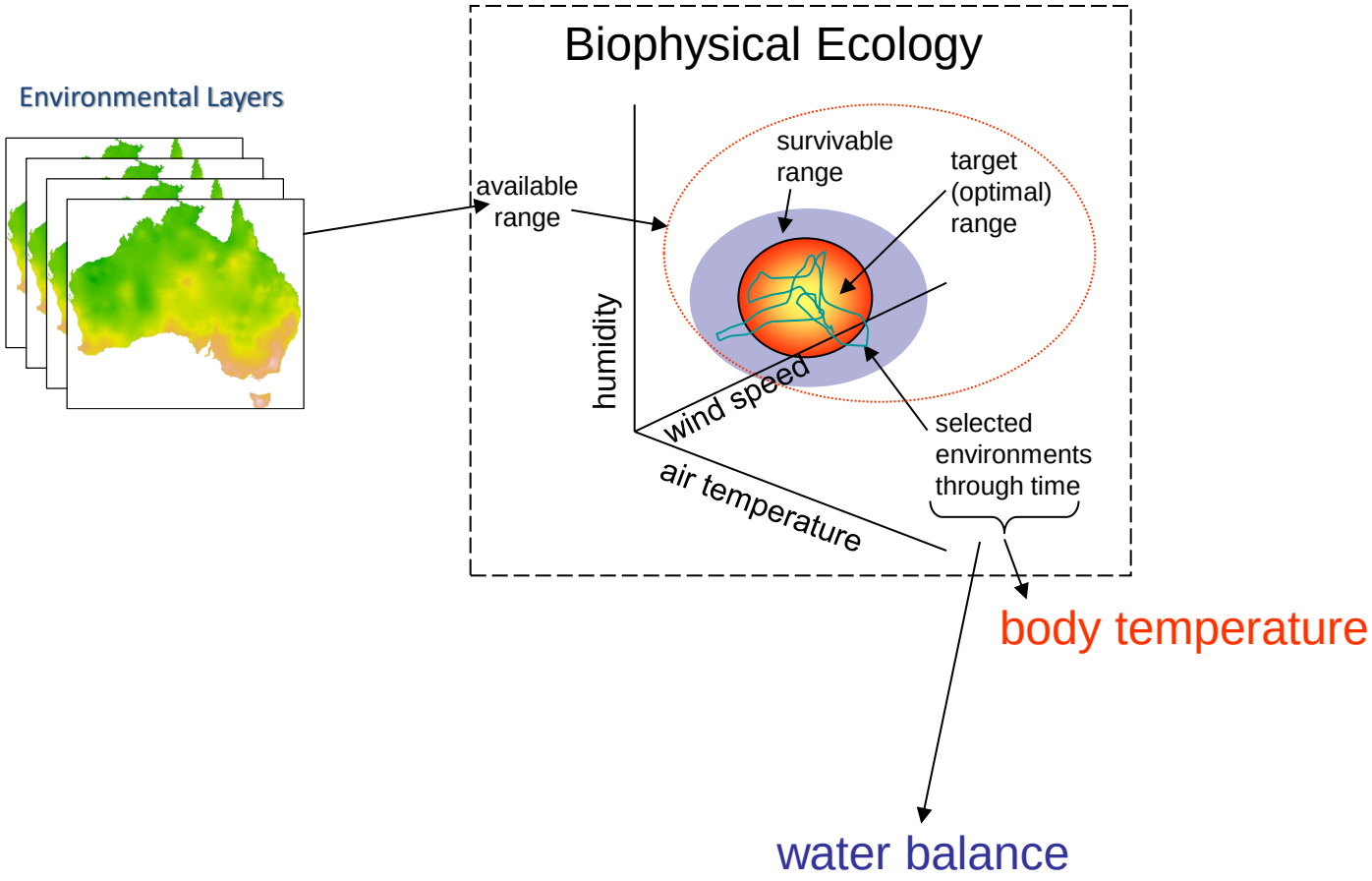
$$Q_{evap,cut} = A_{evap} h_d (V_{d,skin} - V_{d,air}) \lambda$$

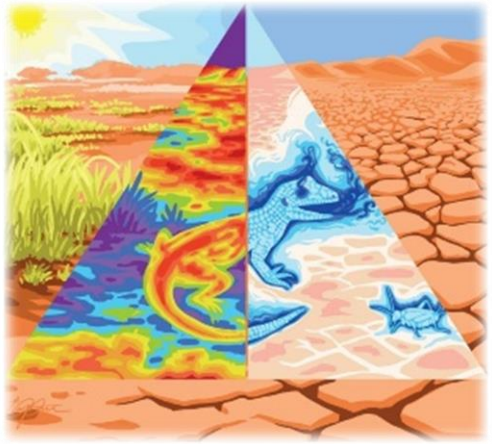
mass transfer coefficient

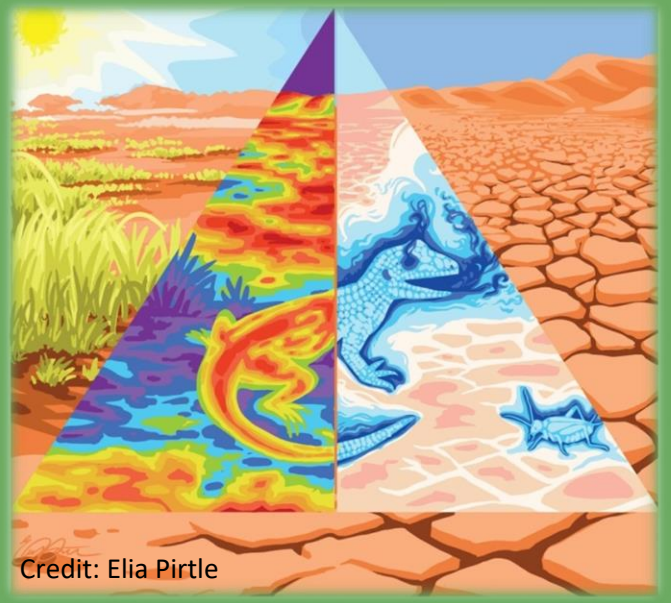
vapor density,

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

Thermodynamic basis to the niche







Credit: Elia Pirtle

3.

Connecting to DEB theory

Inferring climatic constraints

Incorporating nutritional constraints

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
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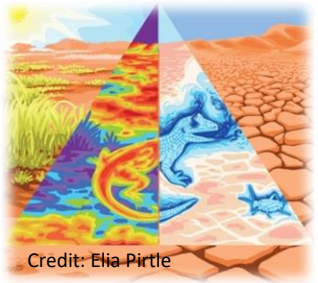
$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{J\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P} = p_{IR,out} + J_{CO2,MET} + J_{N,MET}$$

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


Credit: Elia Pirtle

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)

Thermodynamic basis to the niche

p_{SOLAR} + $p_{IR,in}$ + $J_{O2,MET}$ + $J_{CO2,MET}$ + $J_{N,MET}$ + $J_{H,I}$ + $J_{H,MET}$ = $J_{H,U}$ + $J_{H,P}$ + $J_{H,S}$ + p_{EVAP} + p_{COND} = $p_{IR,out}$ + p_{CONV} + heat

$J_{X,I}$ = p_J + $J_{X,G}$ + $J_{X,R}$ + $J_{X,S}$ + $J_{X,P}$ (MET)

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
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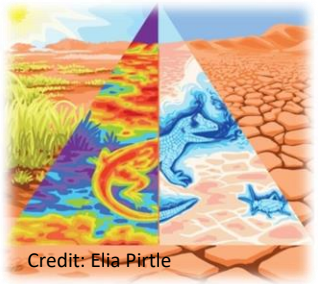
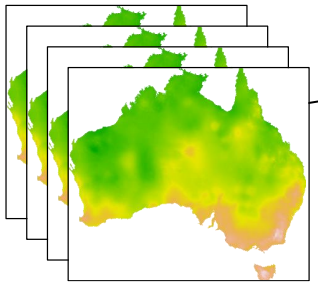
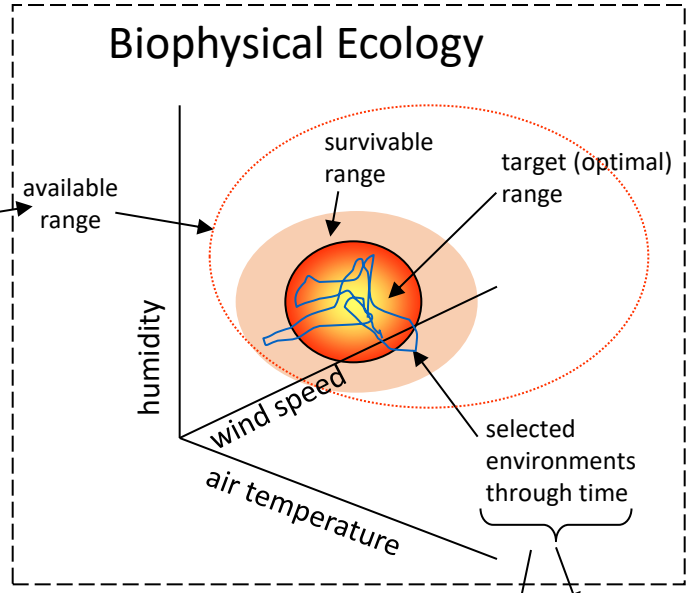

Credit: Elia Pirtle

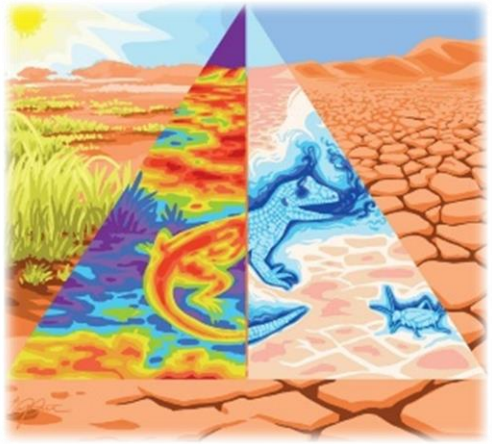
$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

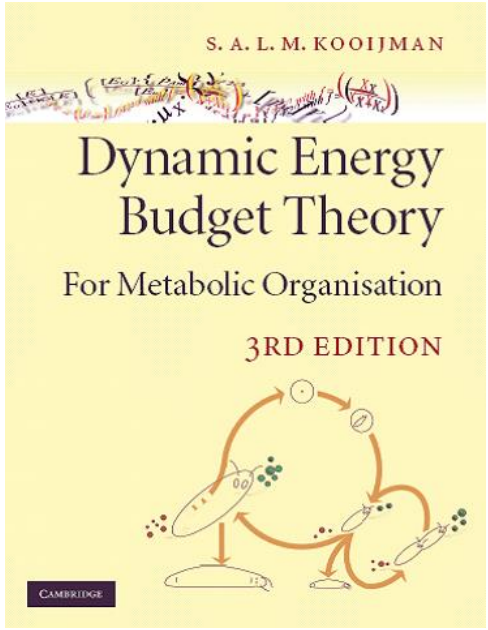
Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

Thermodynamic basis to the niche





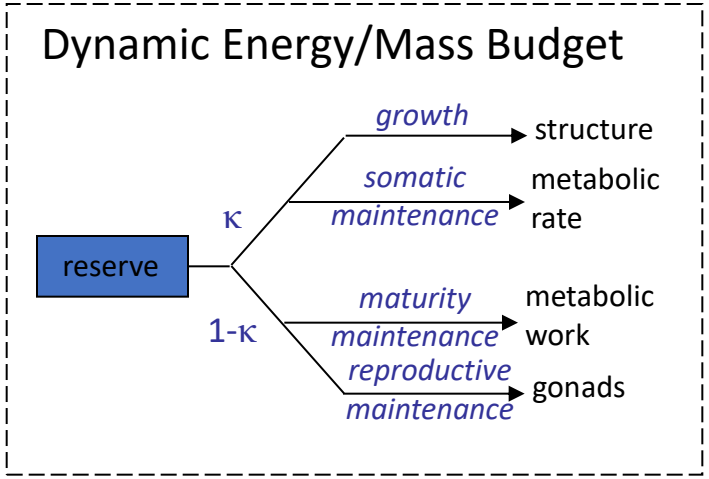




body temp/metabolic rate

physiological rates

water balance



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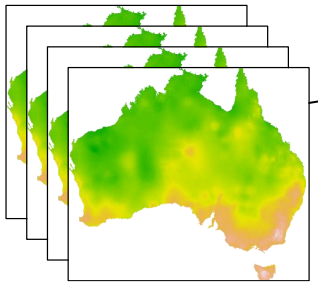
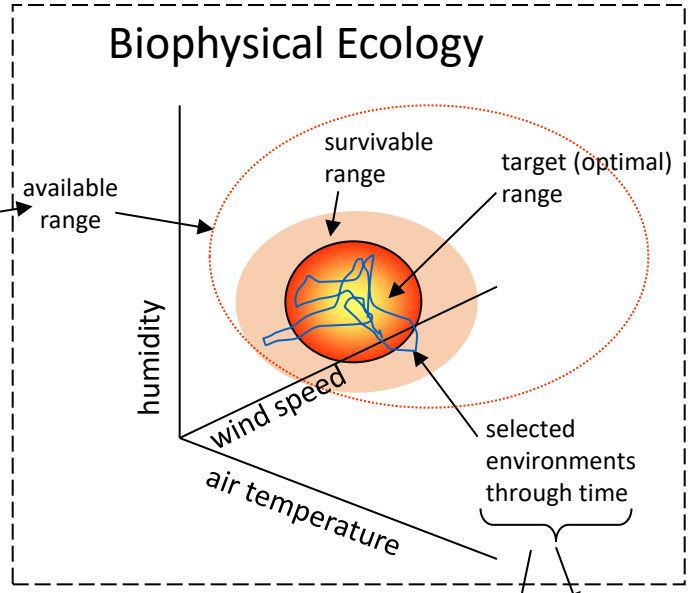
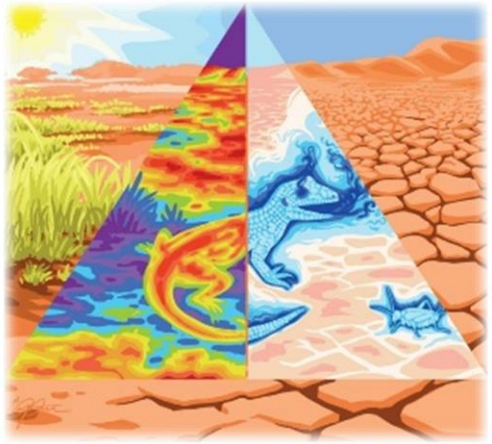
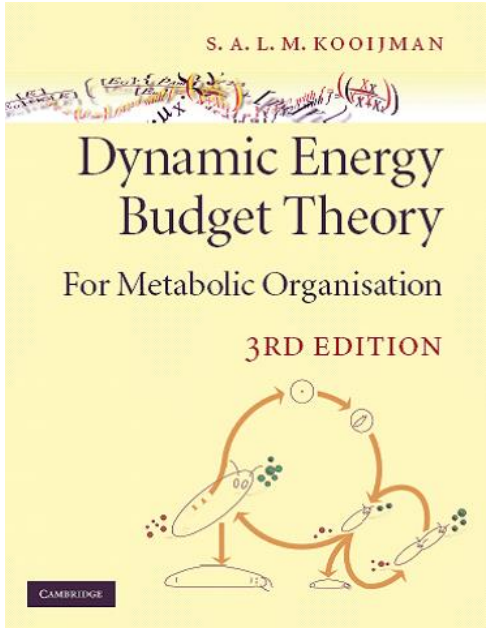
Thermodynamic basis to the niche









body temp/metabolic rate

physiological rates

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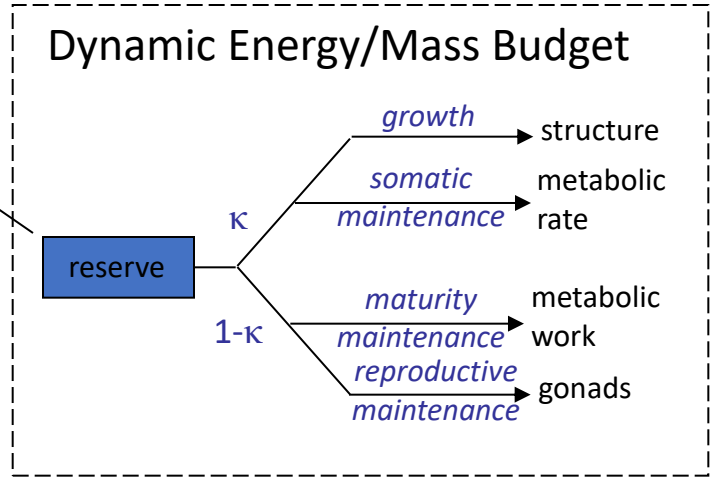
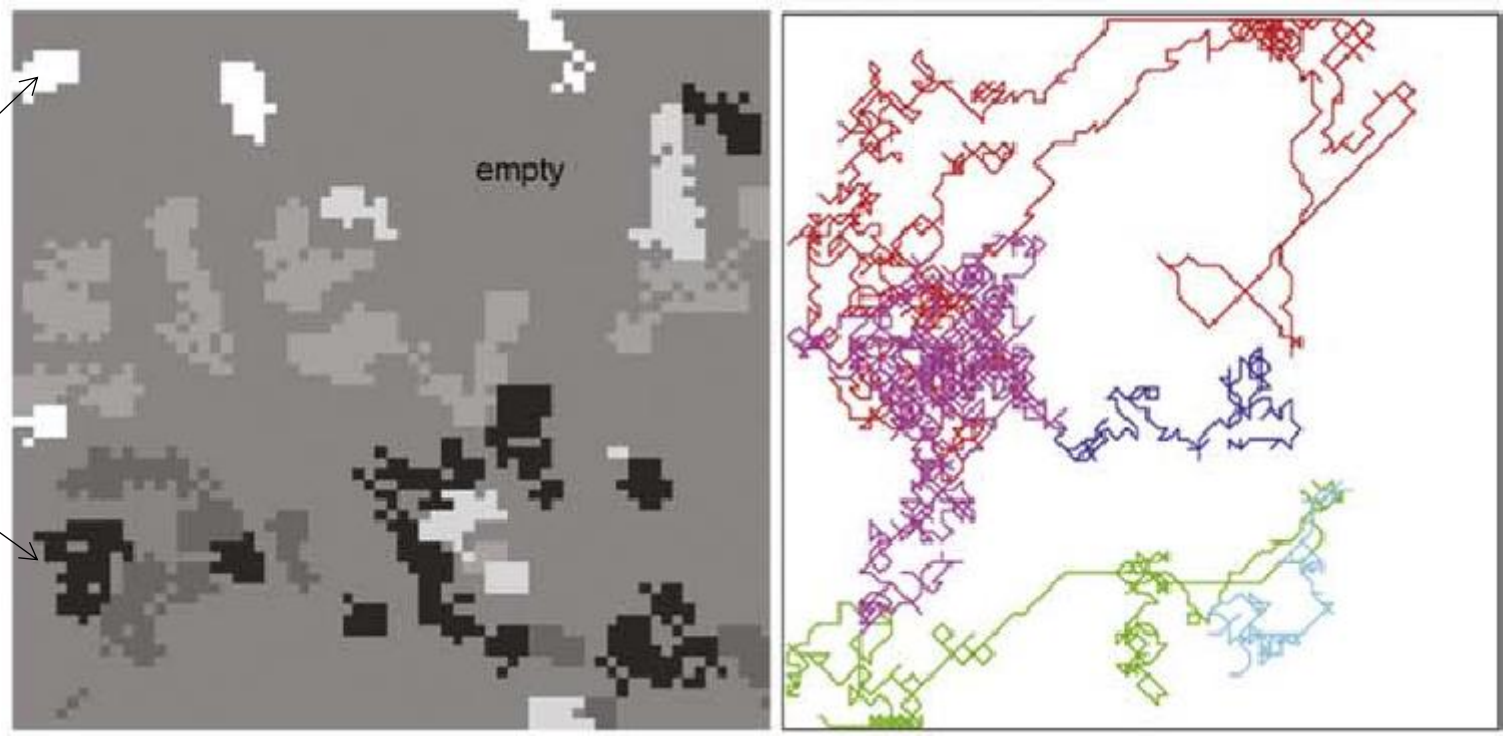


Incorporating nutritional constraints

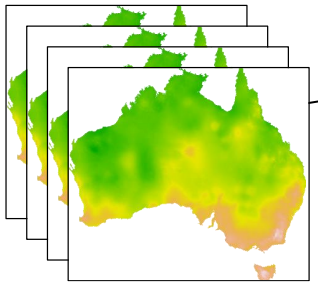
Nutritional Landscape

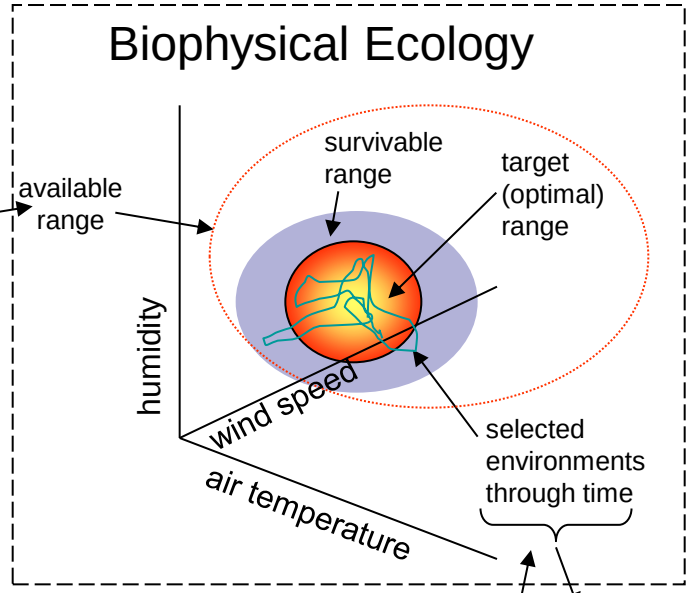
high P:C

low P:C



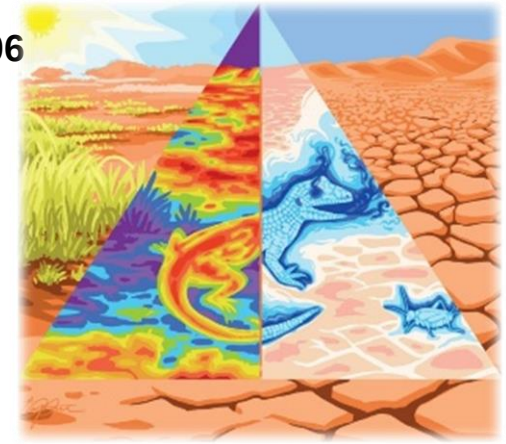
Thermodynamic basis to the niche

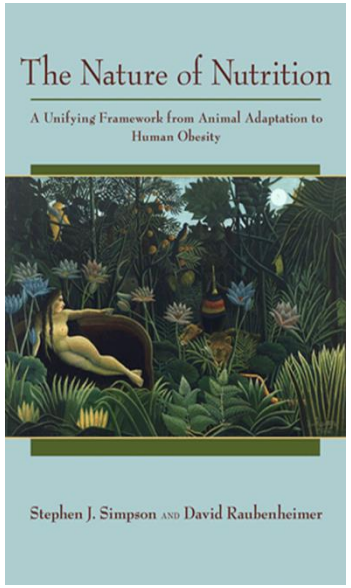




Kearney and Porter TREE 2006

Kearney et al. PTRS 2010



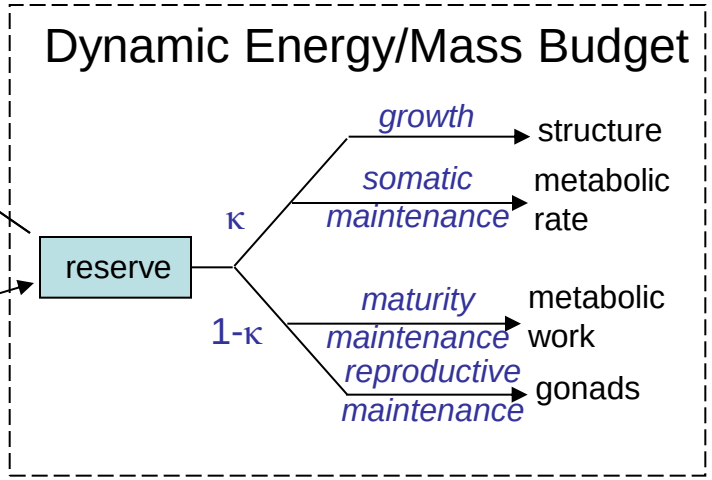


body temp/metabolic rate

physiological rates

water balance

food ingested



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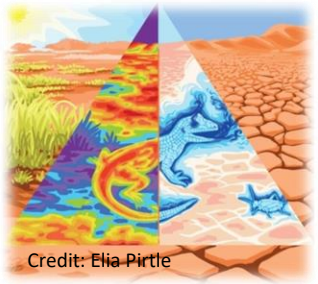
$$J_{CO2,MET} + p_{IR,out} + J_{N,MET} + p_{CONV} = J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \{J\}_{EVAP} + p_{COND}$$



heat

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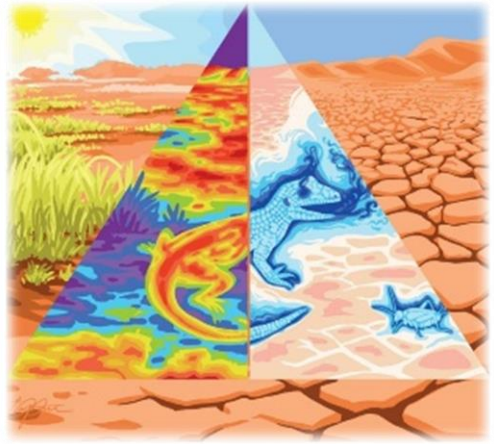
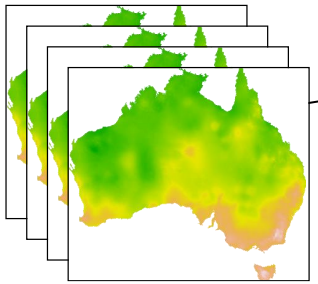
Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)

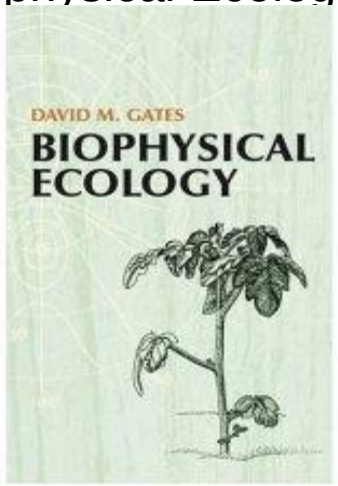
Thermodynamic basis to the niche



Environmental Layers



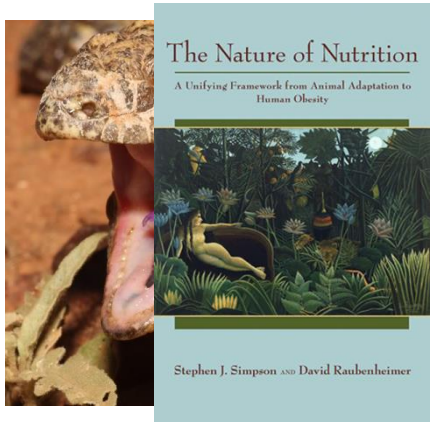
Biophysical Ecology



body temp/metabolic rate

physiological rates

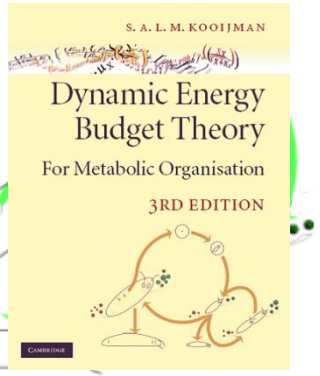
Nutritional Ecology



water balance

food ingested

Dynamic Energy/Mass Budget



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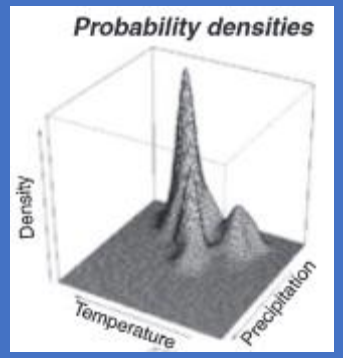
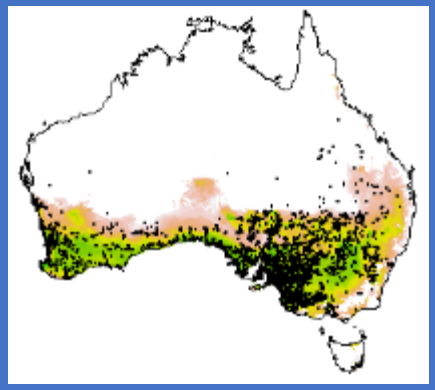
What is a mechanistic niche model?

Correlative Model (process implicit)

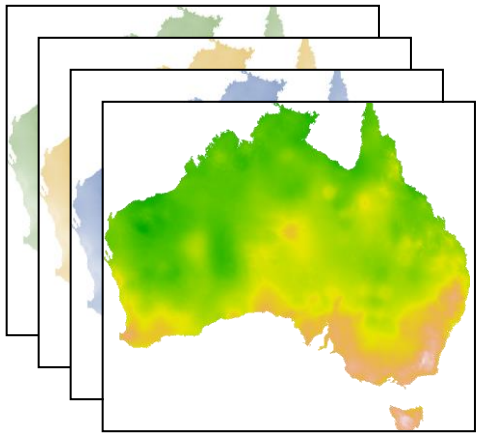
Maxent model



probability of occurrence



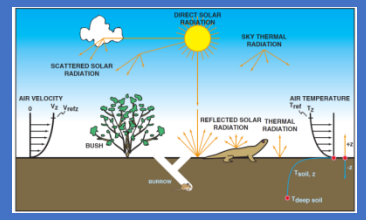
Environmental Layers



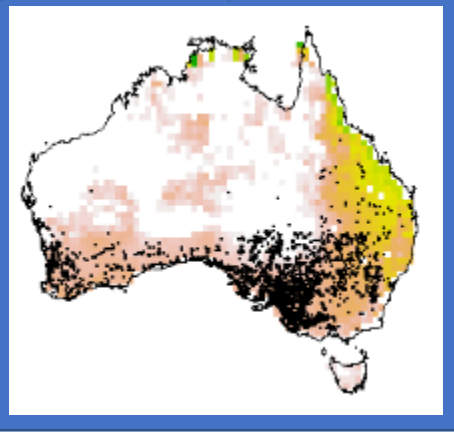
* starts with occurrence records

Mechanistic Model (process explicit)

NicheMapR model



potential reproduction



* starts with functional traits

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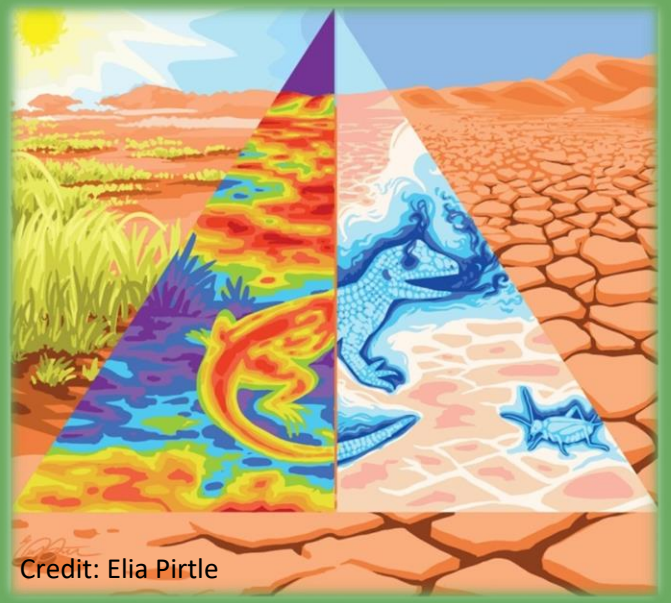

Credit: Elia Pirtle

4.

Functional traits and mechanistic niche models

Dynamical systems models

Theoretical types of functional traits

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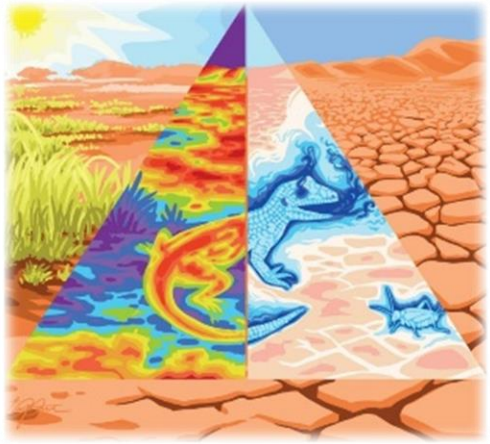
Functional Ecology | BRITISH ECOLOGICAL SOCIETY

PERSPECTIVE

Where do functional traits come from? The role of theory and models

Michael R. Kearney[1] | Marko Jusup[2] | Melodie A. McGeoch[3] | Sebastiaan A. L. M. Kooijman[4] | Steven L. Chown[5]



REAL WORLD

ABSTRACT WORLD

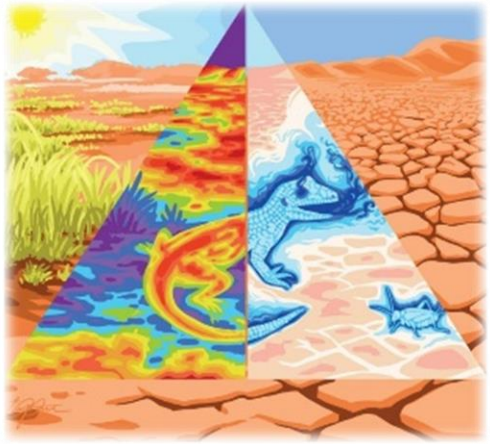
$$\frac{\mathrm{d}}{\mathrm{d}t} i\text{-state} = \textsc{Flow}(e\text{-state}, i\text{-state}; \boldsymbol{\lambda})$$

MODEL

THEORY

ABSTRACT WORLD

REAL WORLD



REAL WORLD

ABSTRACT WORLD

INITIAL STATE

body size
body temp.
water content

$$\frac{\mathrm{d}}{\mathrm{d}t} i\text{-state} = \textsc{Flow}(e\text{-state}, i\text{-state}; \boldsymbol{\lambda})$$

MODEL

THEORY

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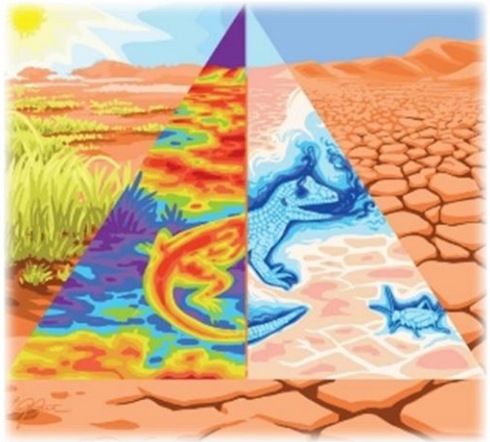
REAL WORLD



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MODEL

THEORY

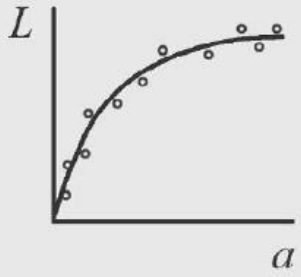
FUTURE STATE

body size
body temp.
water content

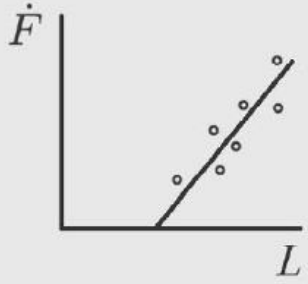
ABSTRACT WORLD
REAL WORLD

PERFORMANCE

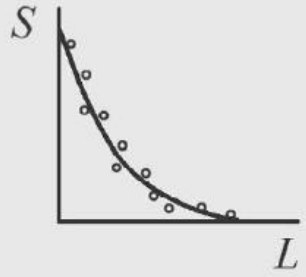
▸GROWTH
length-age

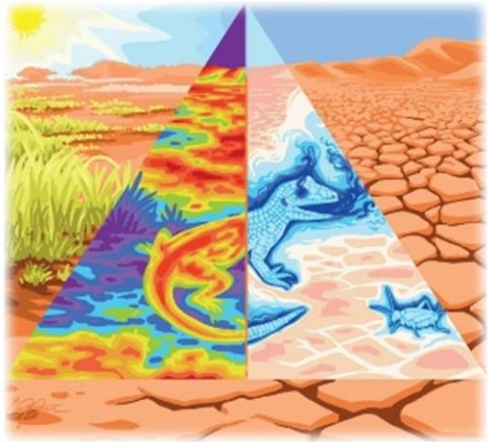


▸REPRODUCTION
fecundity-length



▸SURVIVAL
probability-length





ENVIRONMENTAL DATA

REAL WORLD

ABSTRACT WORLD

ENVIRONMENTAL FORCINGS

food
temperature
humidity

INITIAL STATE

body size
body temp.
water content

$$\frac{\mathrm{d}}{\mathrm{d}t} i\text{-state} = \mathrm{FLOW}(e\text{-state}, i\text{-state}; \boldsymbol{\lambda})$$

MODEL

THEORY

FUTURE STATE

body size
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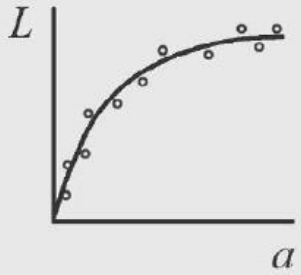
ABSTRACT WORLD

REAL WORLD

PERFORMANCE

▸GROWTH
length-age



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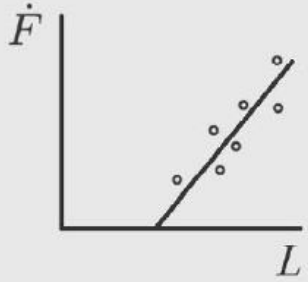

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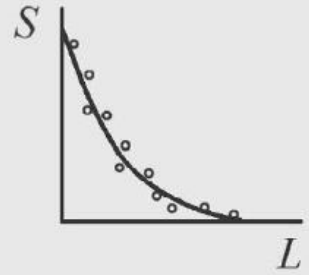

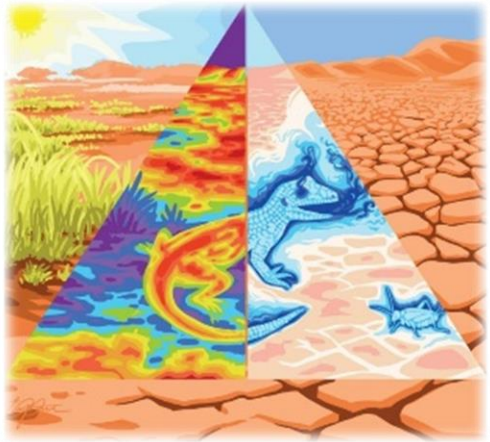

ENVIRONMENTAL DATA

TRAIT DATA

REAL WORLD

ABSTRACT WORLD

ENVIRONMENTAL FORCINGS

INITIAL STATE

PARAMETERS

food
temperature
humidity

body size
body temp.
water content

maintenance rate
insulation
target body temp.

$$\frac{\mathrm{d}}{\mathrm{d}t} i\text{-state} = \text{FLOW}(e\text{-state}, i\text{-state}; \boldsymbol{\lambda})$$

MODEL

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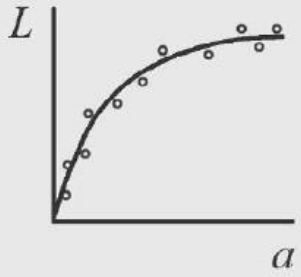

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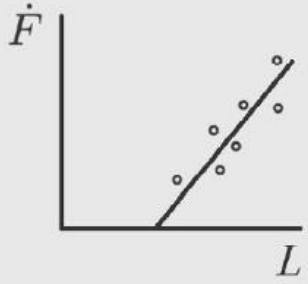

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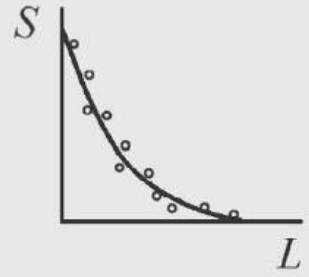

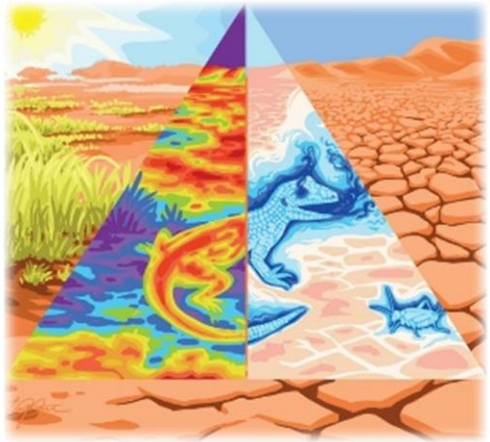

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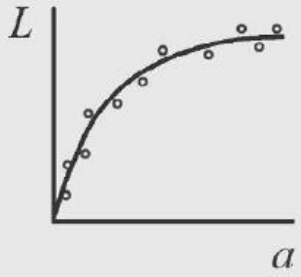

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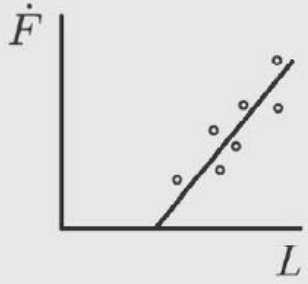

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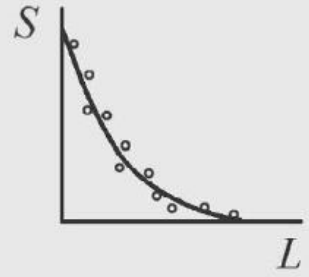


Thermodynamic basis to the niche

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

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

$$J_{CO2,MET} + p_{IR,out} + J_{N,MET} + p_{CONV}$$

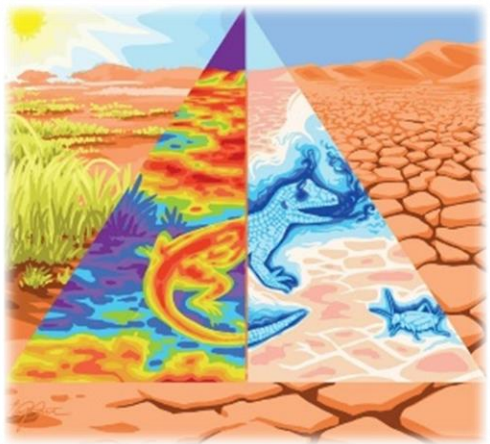
$$J_{H,I} + J_{H,MET} = J_{H,U} + J_{H,P} + J_{H,S} + \{J, p\}_{EVAP} + p_{COND} + p_S$$

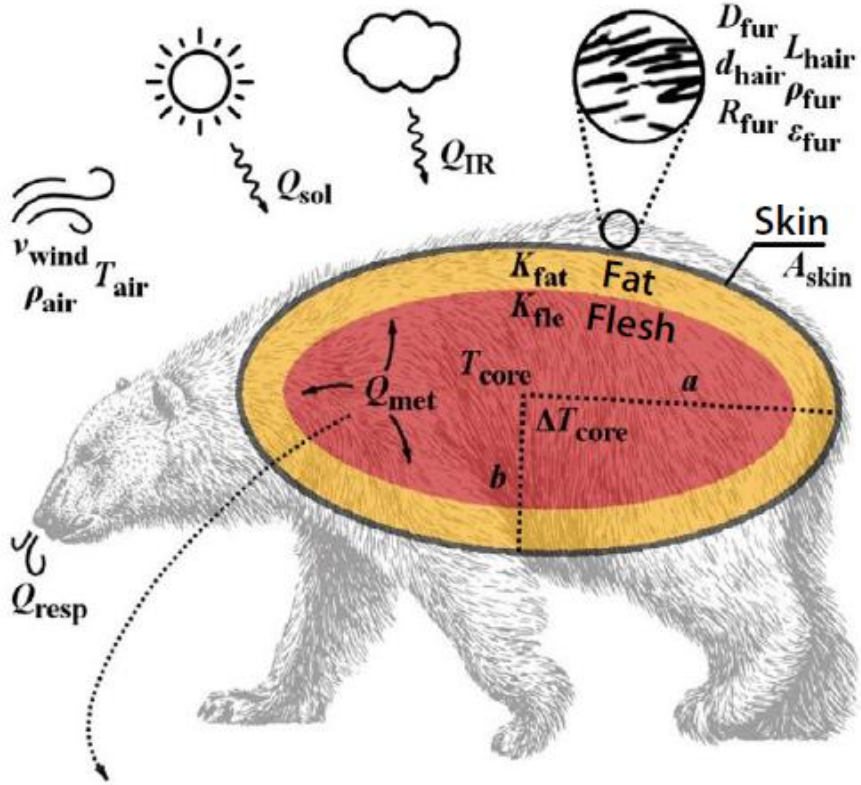
heat

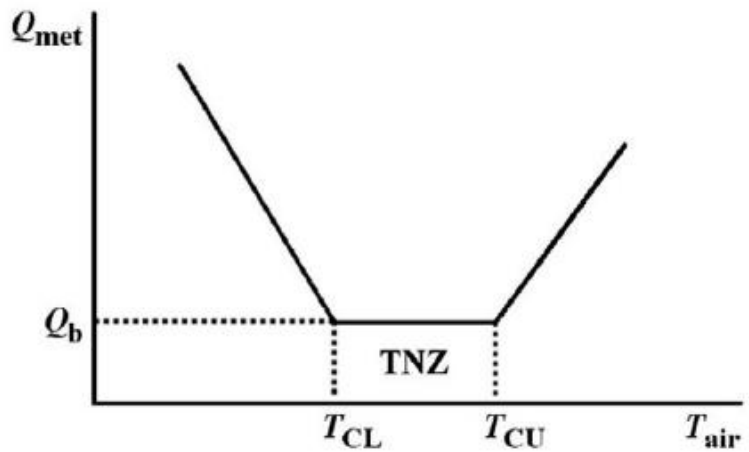
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$

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

Credit: Elia Pirtle







Environmental forcings

- Wind speed v_{wind}
- Air temperature T_{air}
- Vapour density ρ_{air}
- Solar radiation Q_{sol}
- Infrared radiation Q_{IR}

Functional traits

- Fur depth D_{fur}
- Hair length L_{hair}
- Hair diameter d_{hair}
- Fur density ρ_{fur}
- Fur reflectance R_{fur}
- Fur emissivity ε_{fur}
- Skin surface area A_{skin}
- Fat heat conduct. K_{fat}
- Flesh heat conduct. K_{fle}
- Target core temp. T_{core}
- Body shape a/b
- Basal metabolism Q_b

Processes

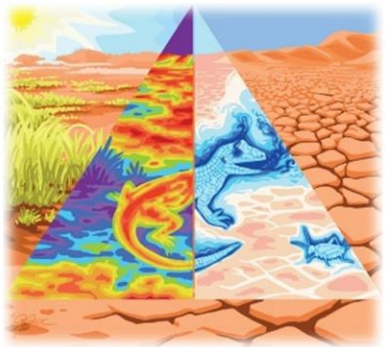
- Metabolic rate Q_{met}
- Respiration Q_{resp}

State variable

- Temp. deviation ΔT_{core}
- Body size a

Other

- Lower critical temp. T_{CL}
- Upper critical temp. T_{CU}



MEASURABLE ASPECT OF AN ORGANISM
- *descriptive process*
- *descriptive state*
- *functional state*

EXTERNAL TO THE ORGANISM? ✓ ✗
- *air temperature*
- *lower critical (air) temperature*
- *solar absorptivity*
- *metabolic rate*
- *lethal temperature*
- *body temperature*
- *thermo-regulatory mode*
- *fur density*
- *fur colour*

TERM OR RATE IN A DSM* OF THE ORGANISM? ✓ ✗
- *air temperature*
- *lower critical (air) temperature*

ENVIRONMENTAL (FORCING) VARIABLE
- *air temperature*

DESCRIPTIVE CONDITION OR RESOURCE
- *lower critical (air) temperature*

TERM OR RATE IN A DSM OF THE ORGANISM? ✓ ✗
- *solar absorptivity*
- *metabolic rate*
- *lethal temperature*
- *body temperature*
- *thermo-regulatory mode*
- *fur density*
- *fur colour*

CONSTANT† OVER ONTOGENY? ✓ ✗
- *solar absorptivity*
- *metabolic rate*
- *lethal temperature*
- *body temperature*

FUNCTIONAL TRAIT (PARAMETER)
- *solar absorptivity*

EXPRESSED AS RATE OR TIME? ✓ ✗
- *metabolic rate*
- *lethal temperature*
- *body temperature*

FUNCTIONAL PROCESS
- *metabolic rate*

THRESHOLD AT WHICH A DSM ALTERS/FALTERS? ✓ ✗
- *lethal temperature*
- *body temperature*

FUNCTIONAL TRAIT (THRESHOLD)
- *lethal temperature*

FUNCTIONAL STATE VARIABLE
- *body temperature*

DETERMINANT OF DSM STRUCTURE? ✓ ✗
- *thermo-regulatory mode*
- *fur density*
- *fur colour*

FUNCTIONAL TRAIT (MODEL)
- *thermo-regulatory mode*

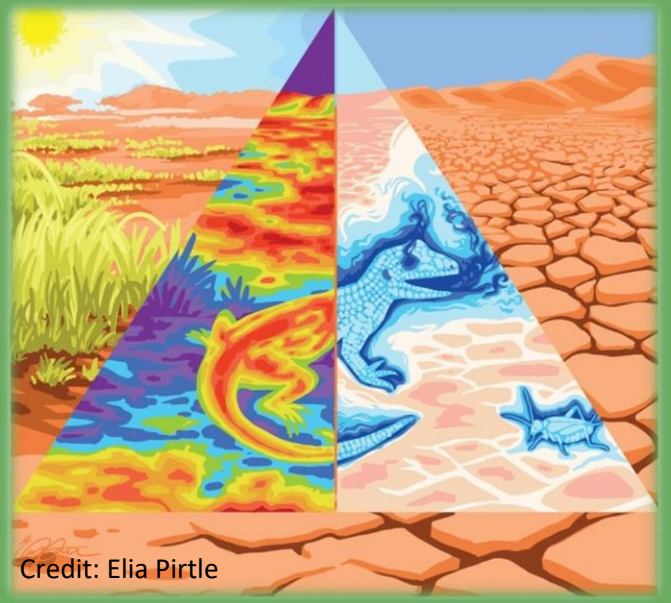
USED TO ESTIMATE A DSM PARAMETER? ✓ ✗
- *fur density*
- *fur colour*

FUNCTIONAL TRAIT (ESTIMATION)
- *fur density*

DESCRIPTIVE TRAIT
- *fur colour*

*DSM = DYNAMICAL SYSTEMS MODEL

†EXCLUDING REACTION NORMS / PLASTICITY



Credit: Elia Pirtle

4.

Ding dong the niche is dead?

Criticism of the niche concept
Individuals to populations

DEB 2025

School: 26 May - 3 Jun 2025

University of Crete, Heraklion, Greece

Integrative and Comparative Biology

Integrative and Comparative Biology, pp. 1–11
doi:10.1093/icb/icz084

Society for Integrative and Comparative Biology

SYMPOSIUM

Fundamental Flaws with the Fundamental Niche

Michael J. Angilletta Jr,[1,*] Michael W. Sears,[†] Ofir Levy,[‡] Jacob P. Youngblood[*] and John M. VandenBrooks[§]

Synopsis For more than 70 years, Hutchinson's concept of the fundamental niche has guided ecological research. Hutchinson envisioned the niche as a multidimensional hypervolume relating the fitness of an organism to relevant environmental factors. Here, we challenge the utility of the concept to modern ecologists, based on its inability to account for environmental variation and phenotypic plasticity. We have ample evidence that the frequency, duration, and sequence of abiotic stress influence the survivorship and performance of organisms. Recent work shows that organisms also respond to the spatial configuration of abiotic conditions. Spatiotemporal variation of the environment interacts with the genotype to generate a unique phenotype at each life stage. These dynamics cannot be captured adequately by a multidimensional hypervolume. Therefore, we recommend that ecologists abandon the niche as a tool for predicting the persistence of species and embrace mechanistic models of population growth that incorporate spatiotemporal dynamics.

Thermodynamic basis to the niche

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

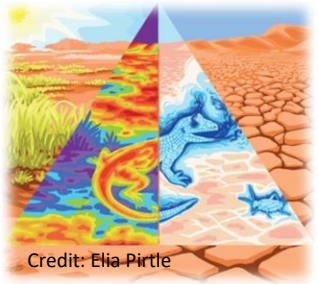
$$p_{SOLAR} + p_{IR,in} + J_{O2,MET} + J_{X,I} = \{J, p\}_{MET} + J_{X,G} + J_{X,R} + J_{X,S} + J_{X,P} = p_{IR,out} + J_{CO2,MET} + J_{N,MET}$$

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

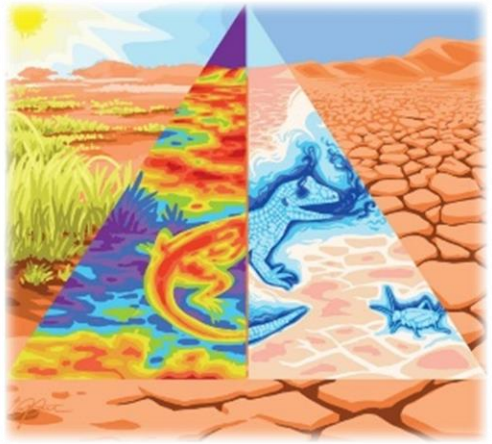
heat

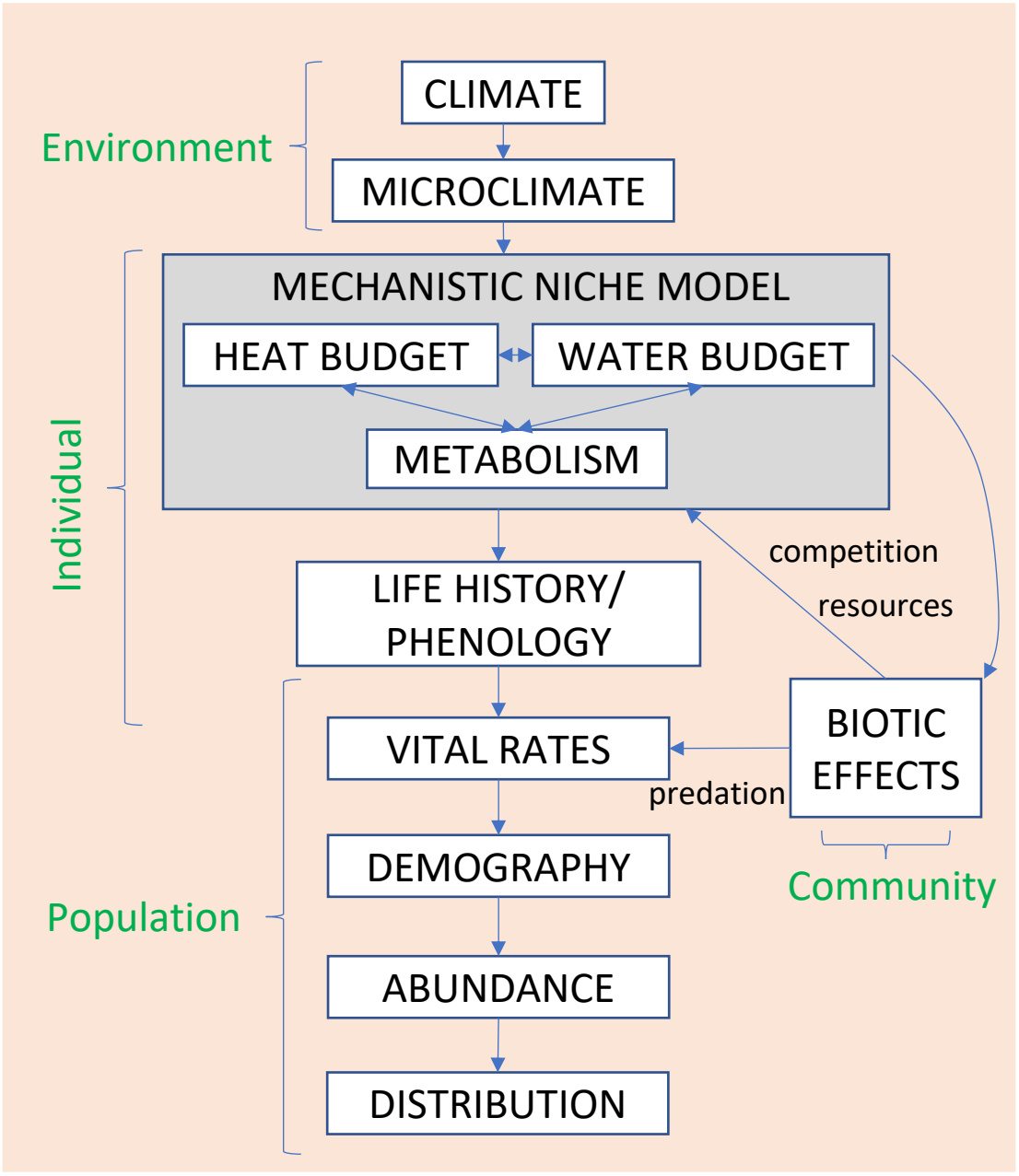
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$

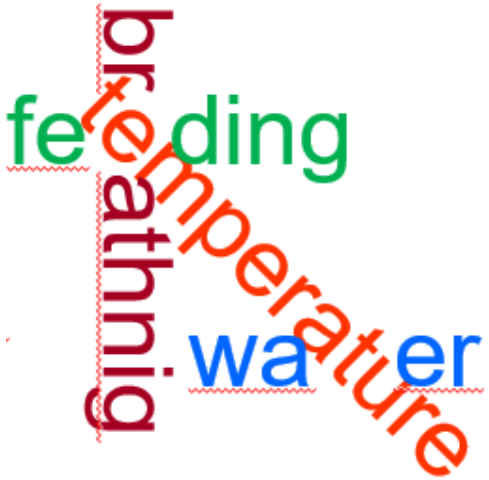
fe ding
breathing
temperature
wa er

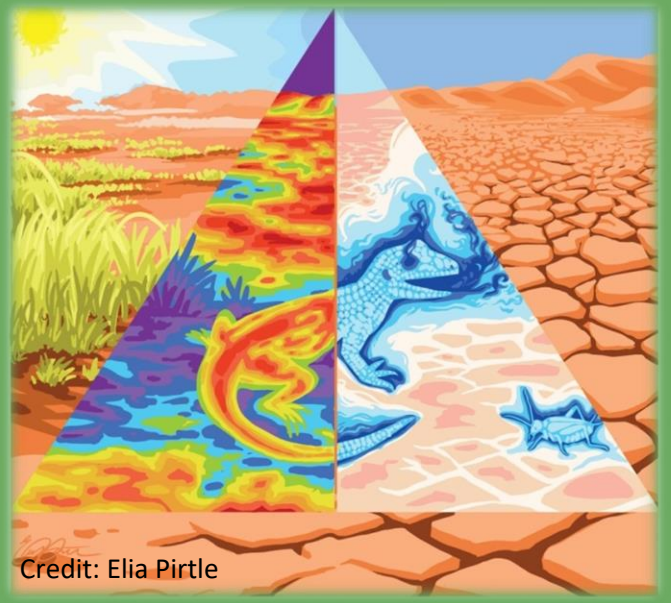

Credit: Elia Pirtle

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




Environment
CLIMATE
MICROCLIMATE
Individual
MECHANISTIC NIKE MODEL
HEAT BUDGET
WATER BUDGET
METABOLISM
LIFE HISTORY/
PHENOLOGY
competition
resources
BIOTIC
EFFECTS
VITAL RATES
predation
DEMOGRAPHY
Community
Population
ABUNDANCE
DISTRIBUTION


feeding
breathing
temperature
water



Credit: Elia Pirtle

5.

Confronting niches with environments

Putting it all together
Simulating trajectories

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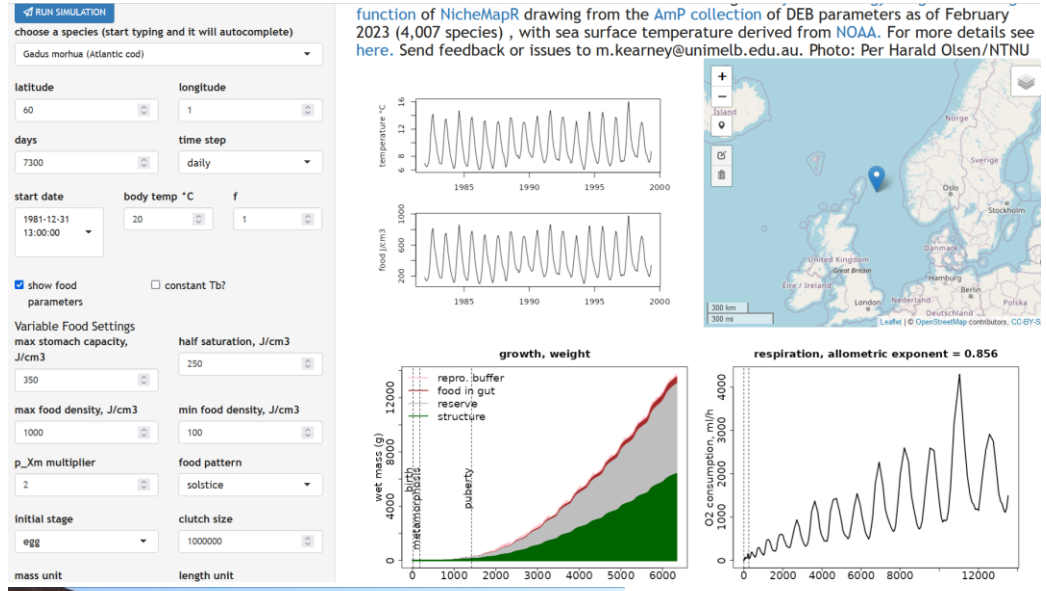
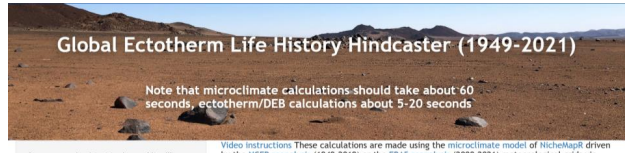
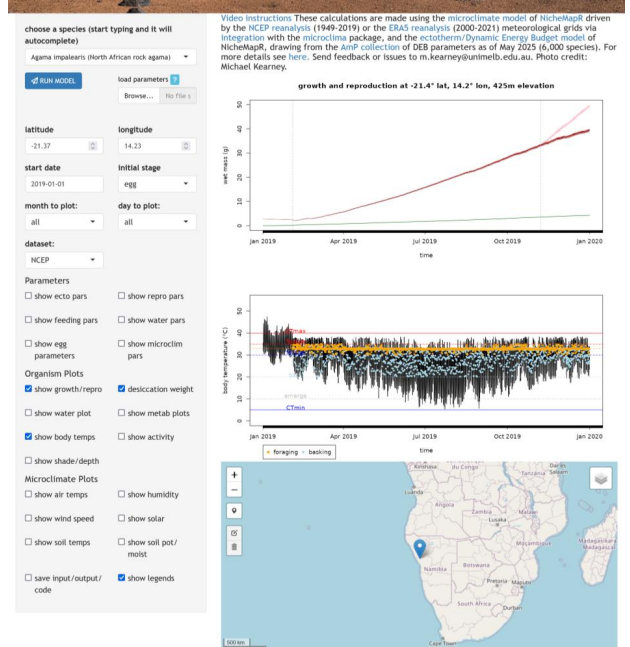
Thank you for your attention

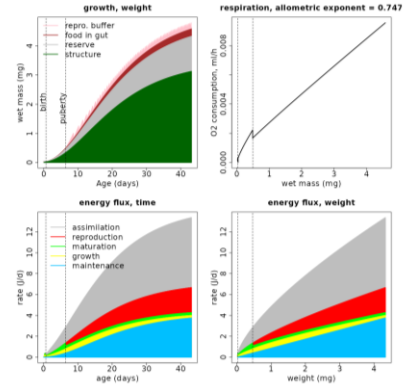
m.kearney@unimelb.edu.au

Simulating trajectories with DEB theory: NicheMapR Shiny Apps









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Home Getting Started People Models Help News Related Projects

NicheMapR

Modelling the thermodynamic constraints on life

Twitter

GitHub

NicheMapR: Software suite for microclimate and mechanistic niche modelling in the R programming environment.

Overview

NicheMapR is a suite of programs for the R environment that compute fundamental physical and chemical constraints on living things. It aims at asking the general question: *Can an organism complete its life cycle in a particular place and time, without overheating, desiccating or starving*?

NicheMapR

Modelling the thermodynamic constraints on life

Twitter

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NicheMapR models are divided into five categories:
Microclimates, Ectotherms, Endotherms, Plants, Dynamic Energy Budgets.

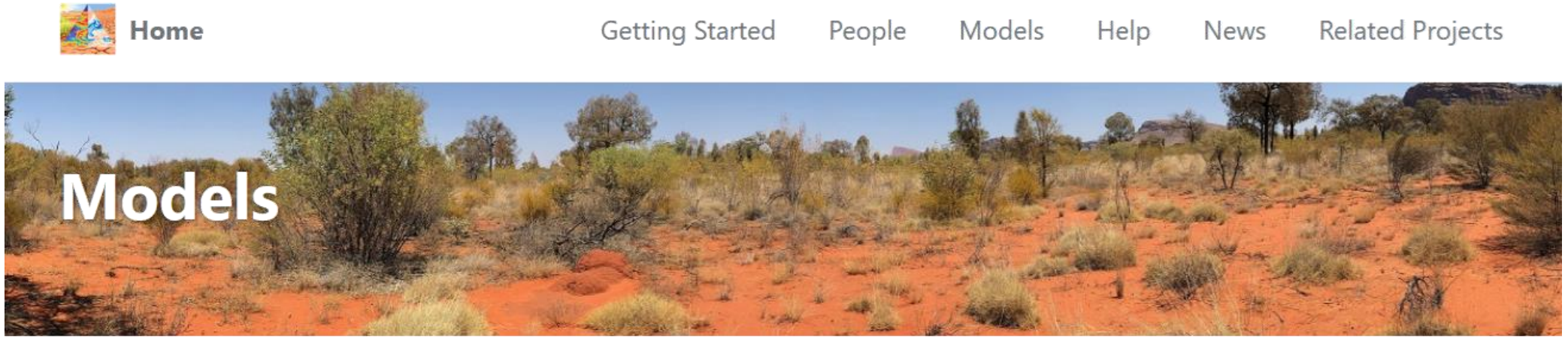
Dynamic Energy Budget Models

Ectotherm Models

Endotherm Models

Microclimate Models

Plant Models



- DEB models included: std, abj, abp, hex, stf
- Full calculation of mass budget – CO_2, O_2, CO_2, H_2O, nitro. waste, etc.
- Three starvation modes – use of reproduction buffer
- Stomach dynamics
- Clutch dynamics

Dynamic Energy Budget Model Demonstration

Runs simulations of species in the AmP DEB parameter database

RUN SIMULATION

choose a species (start typing and it will autocomplete)

Daphnia magna (Waterflea)

days	time step
50	hourly

temperature, °C	f
20	1

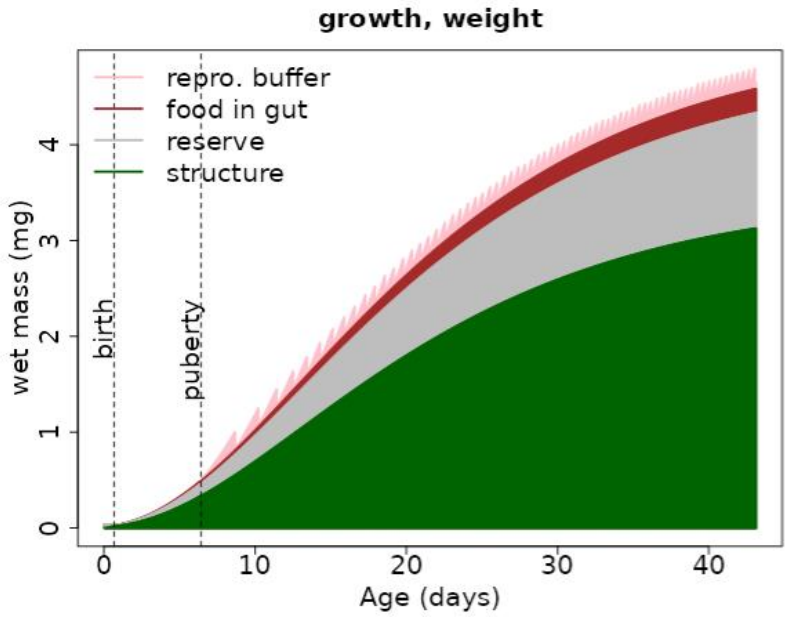
initial stage	clutch size
egg	5

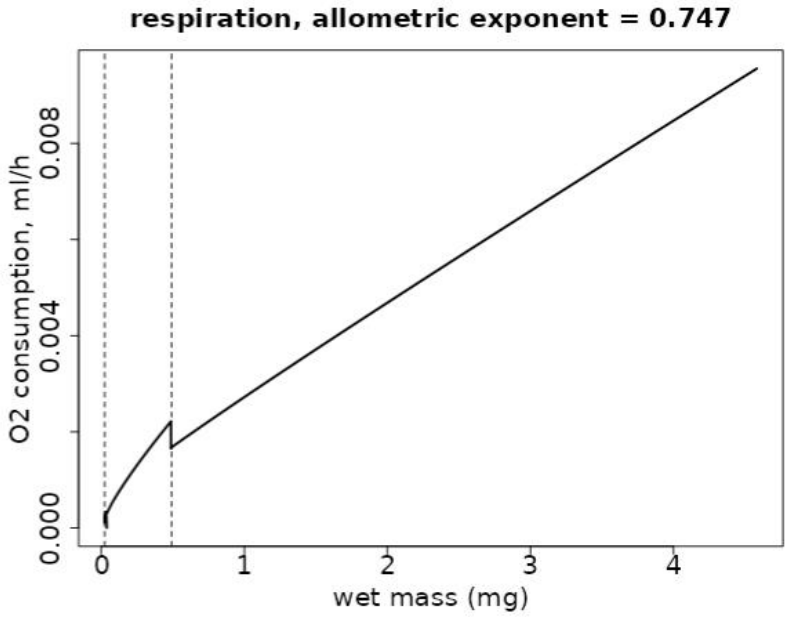
mass unit	length unit
mg	mm

z (size) multiplier - applies DEB covariation rules

0 1 10

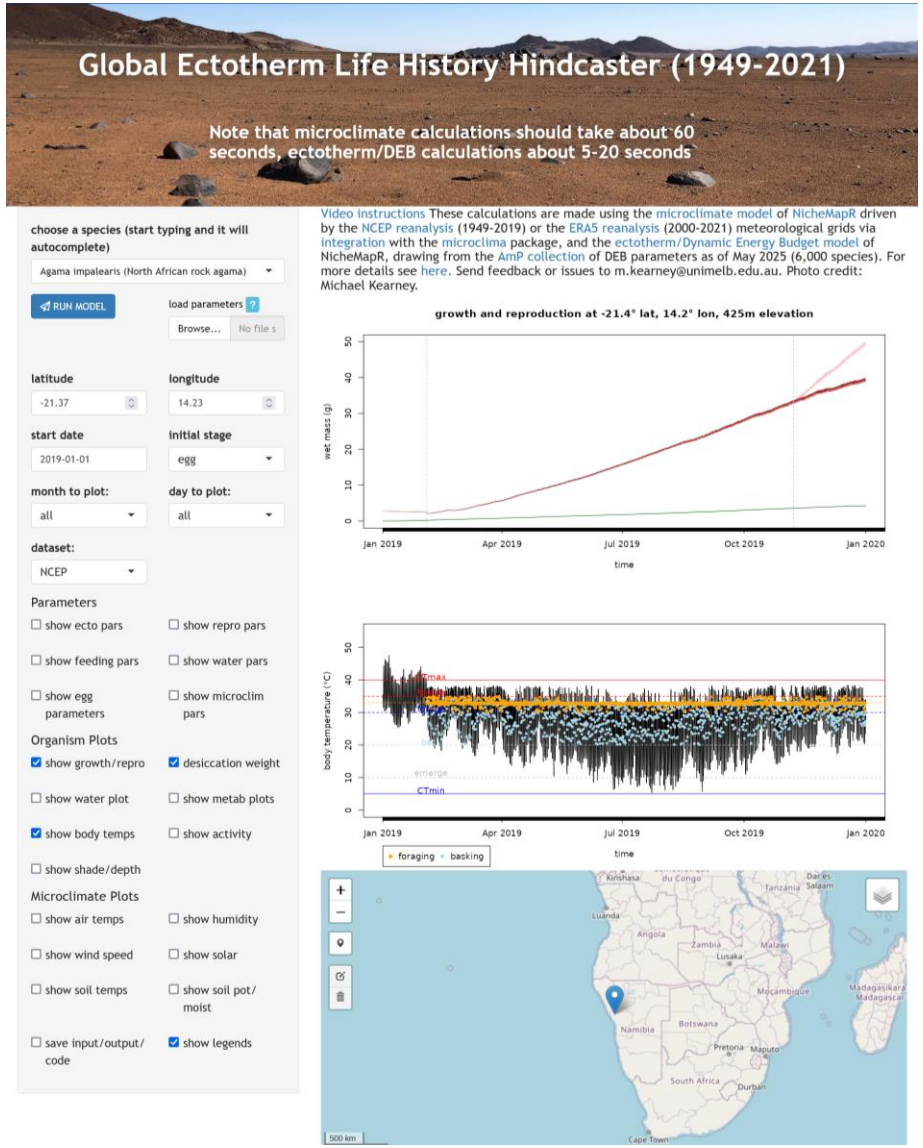
Video instructions These calculations are made using the Dynamic Energy Budget modelling function of NicheMapR drawing from the AmP collection of DEB parameters as of February 2023 (4,007 species). For more details see here. Send feedback or issues to m.kearney@unimelb.edu.au. Photo: Per Harald Olsen/NTNU

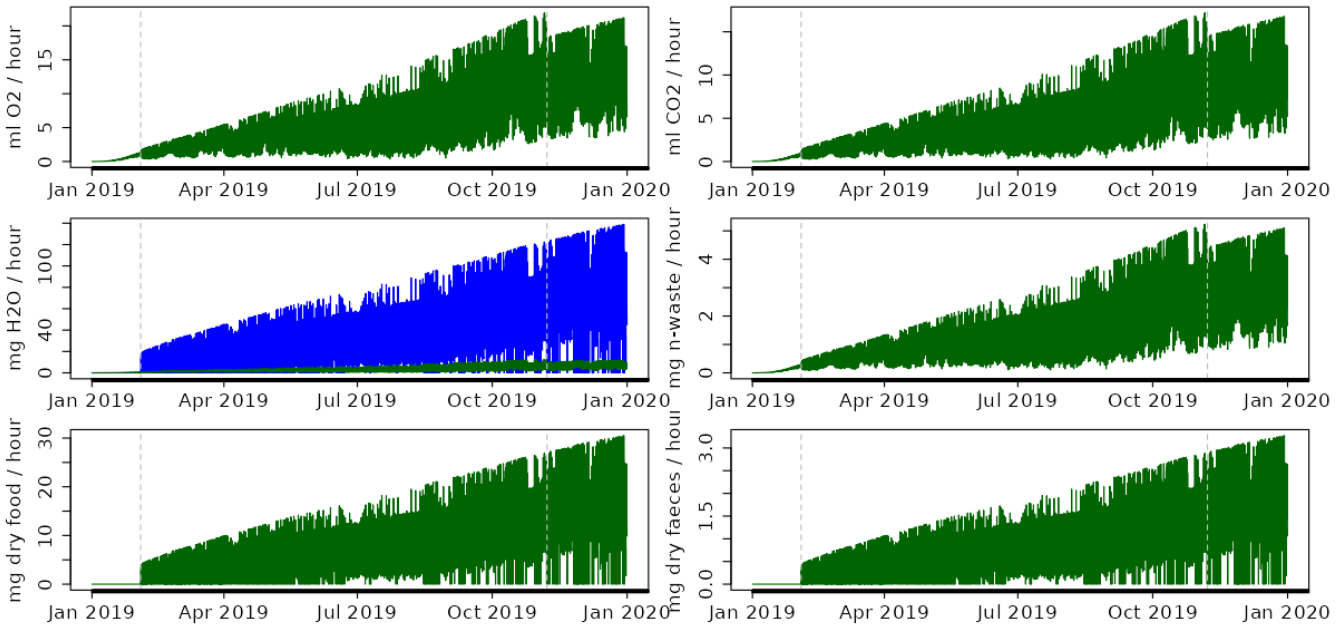


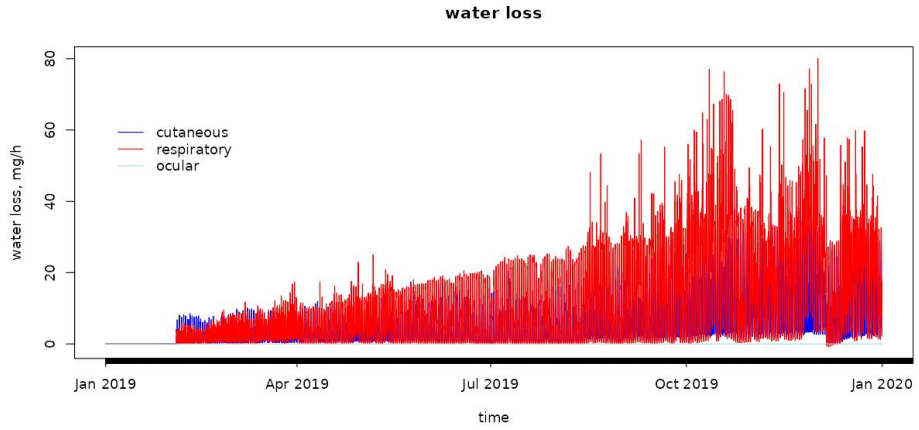


1. Choose a species to simulate
2. decide what time window, step size, temperature and clutch size is appropriate
3. Predict what you think the effects of changing f, temperature, z and kappa should be on
   - maximum mass
   - maximum length
   - time to birth
   - time to maturity
   - time to first clutch
   - fecundity
   - longevity
   - scaling of respiration rate with mass
   - scaling of reproduction rate with mass
   - Can you find any interesting interactions between f, z and kappa?
4. Try running the same organism with deb_sea, look at reproduction scaling

https://camel.science.unimelb.edu.au/biological-forecasting-and-hindcasting-tools/







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