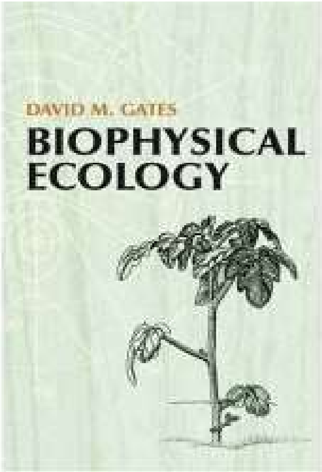
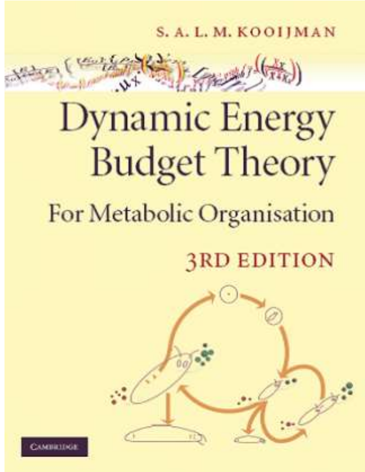
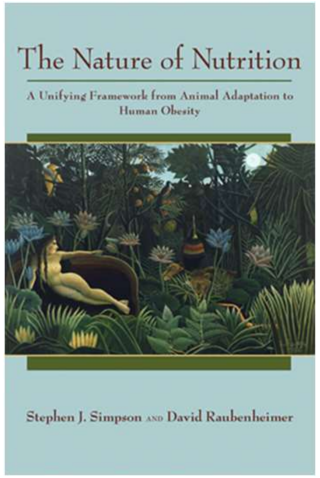




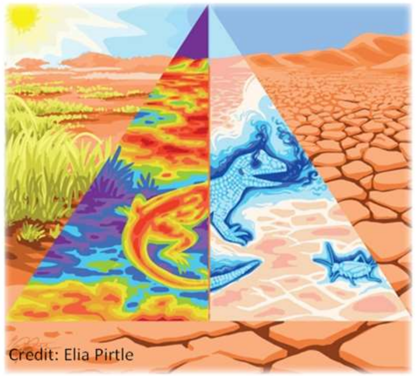


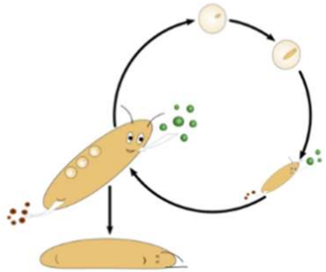
DEB, the Ecological Niche and Functional Traits

Michael Kearney

School of BioSciences

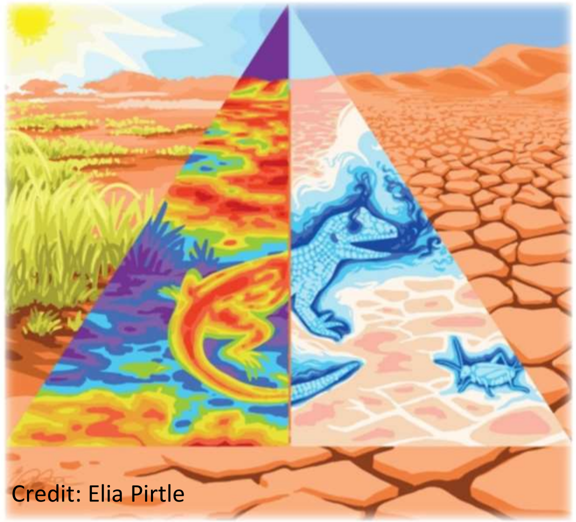
THE UNIVERSITY OF MELBOURNE

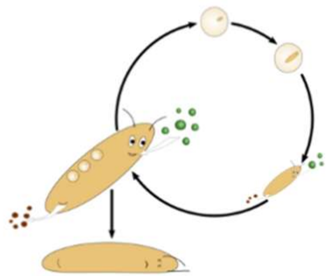


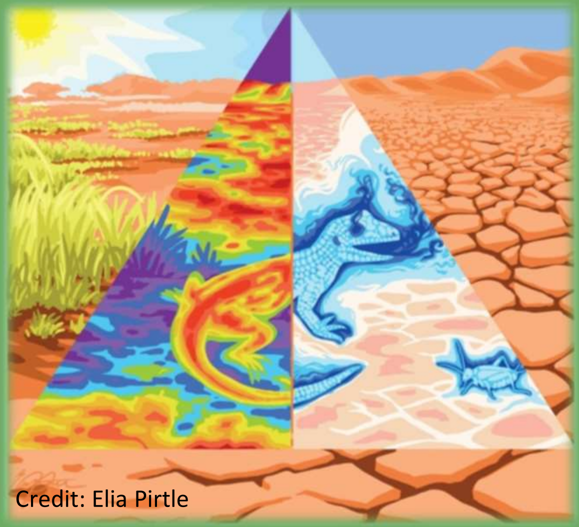


Topics

- What is the ecological niche?
- How can we define the niche thermodynamically?
- Biophysical ecology
- Connecting to DEB theory
- Functional traits and mechanistic niche models

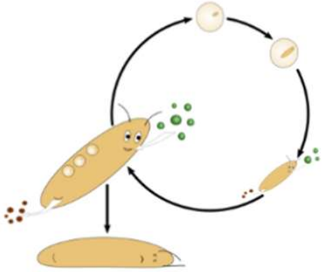






1. What is the ecological niche?

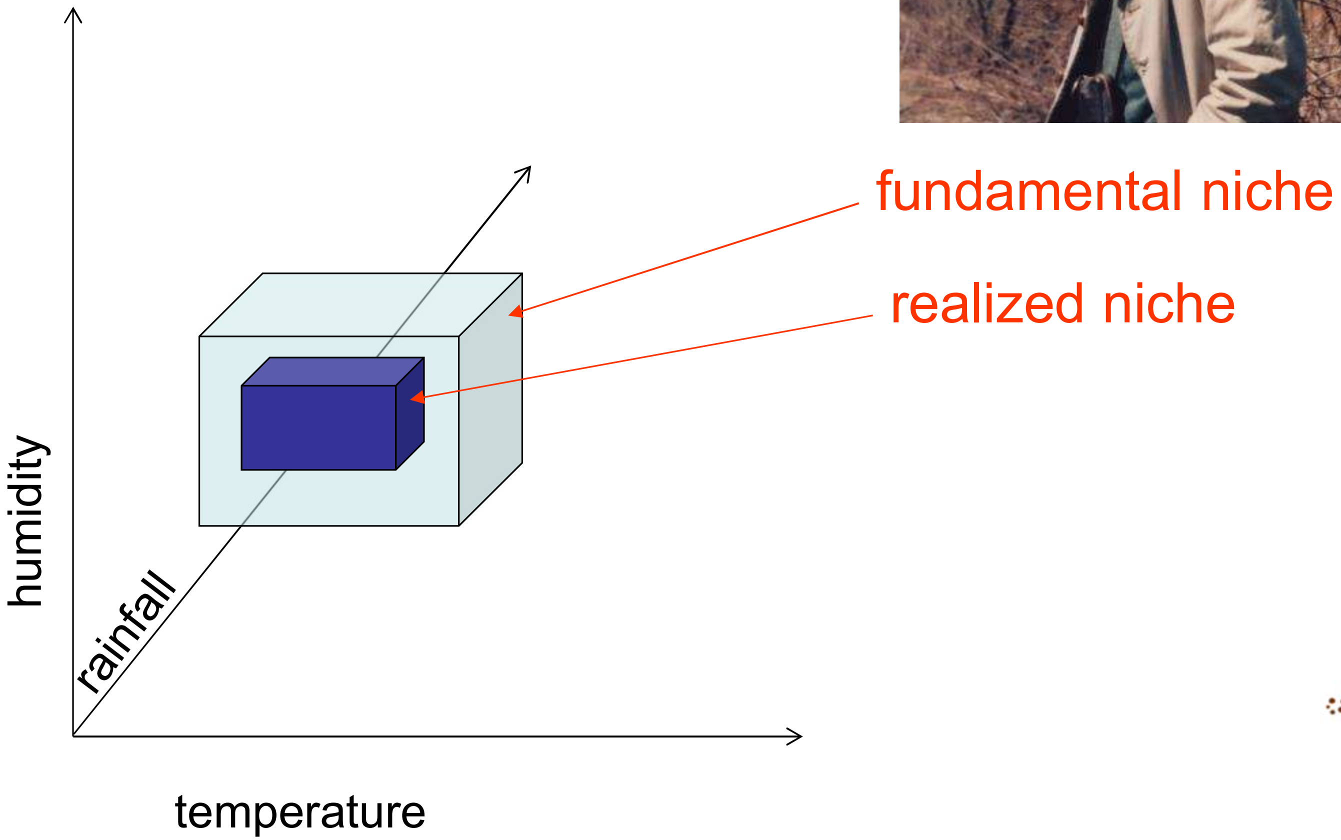
Hutchinsonian niche concept
Modelling the Hutchinsonian niche

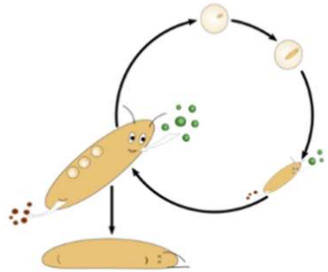


Hutchinsonian niche

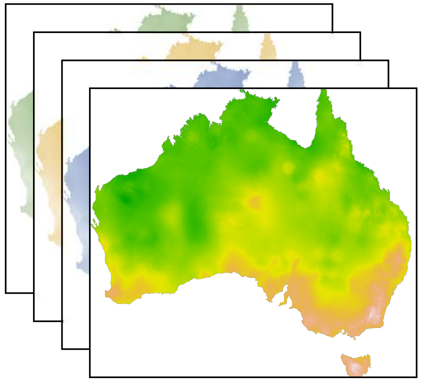
G. Evelyn Hutchinson

Robert H. MacArthur



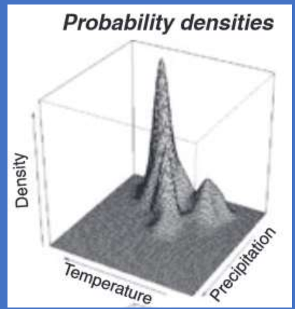


Ecological Niche Modelling

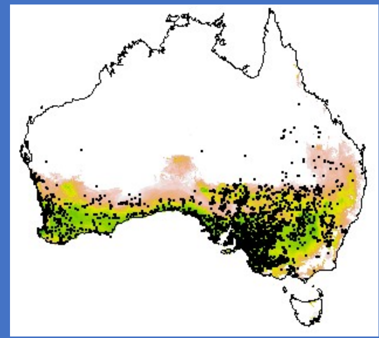


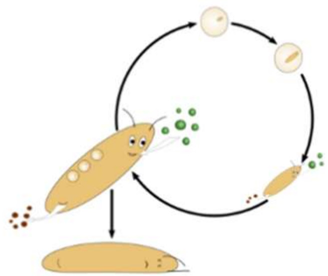
Correlative Model (process implicit)

Maxent model

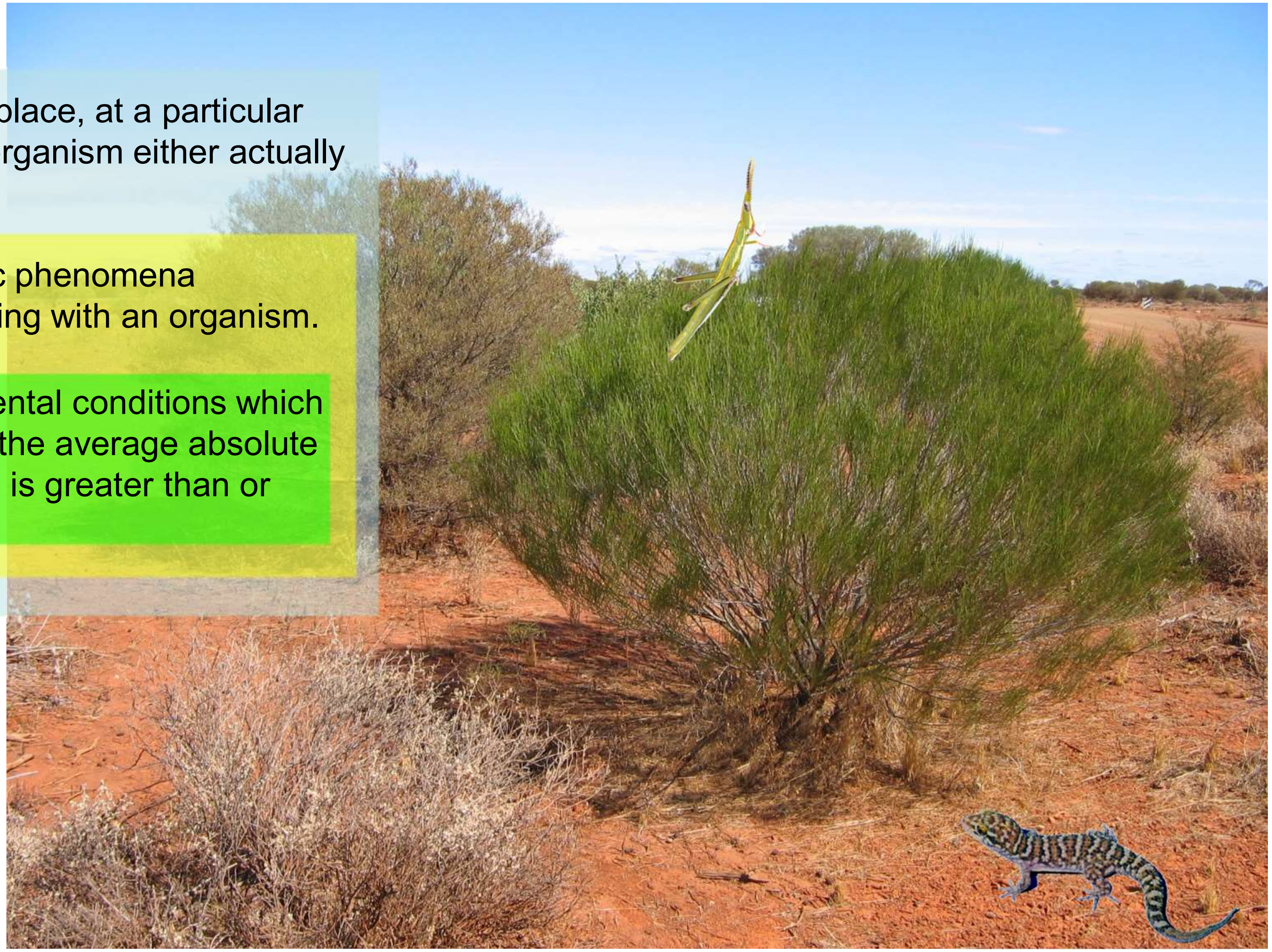


probability of occurrence





Habitat vs. environment vs. niche



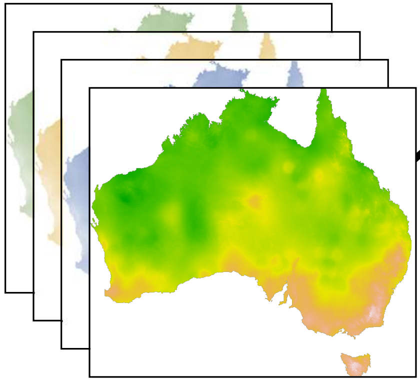
Habitat: a description of a physical place, at a particular scale of space and time, where an organism either actually or potentially lives.

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.

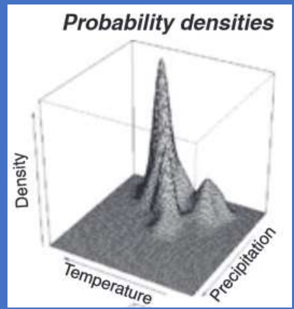
Kearney, M. 2006. Habitat, environment and niche: what are we modelling? — Oikos 115: 186-191.

Ecological Niche Modelling



Correlative Model (process implicit)

Maxent model



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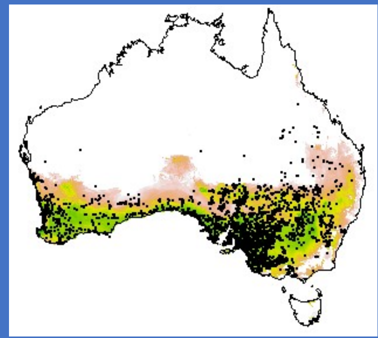
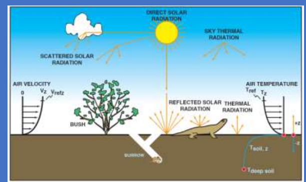
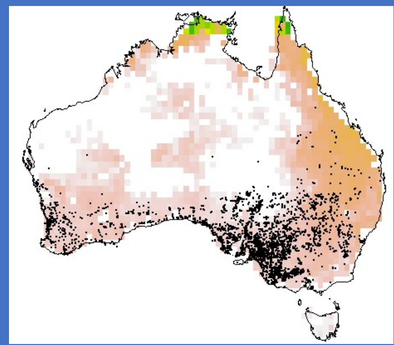


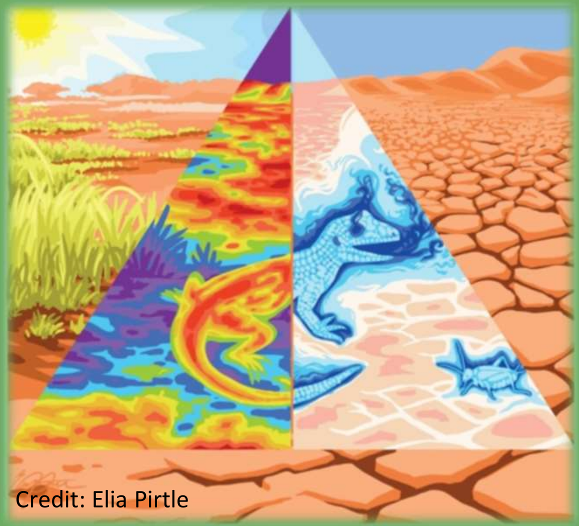
Mechanistic Model (process explicit)

Thermodynamic Niche Model



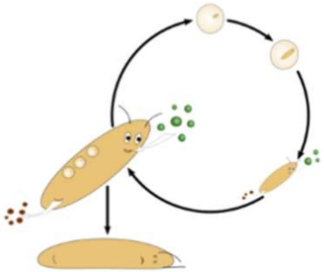
potential reproduction





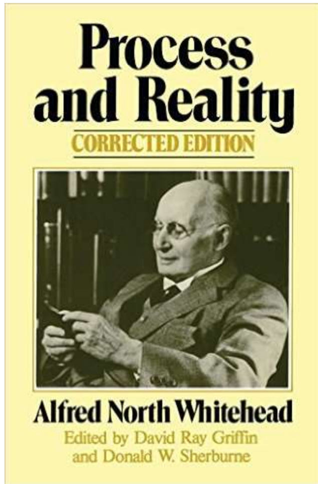
2.
Thermodynamic niche?

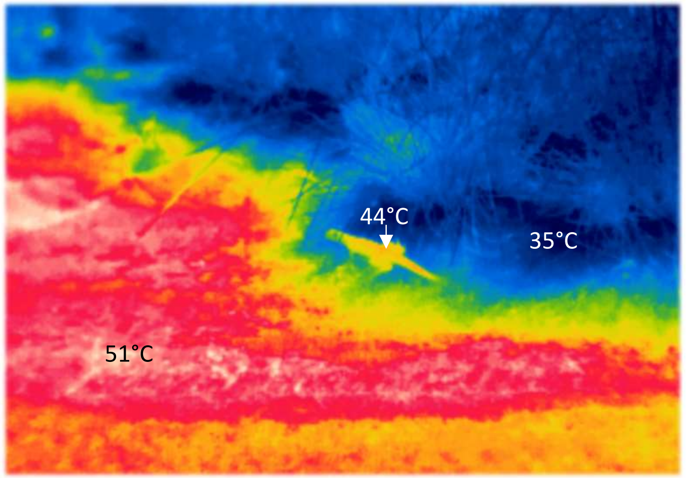
Organisms as thermodynamic systems

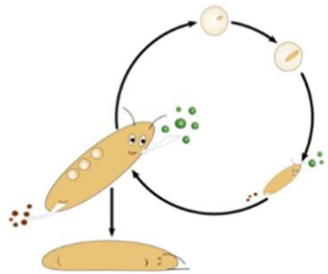


Thermodynamic basis to the niche

Military Dragon, *Ctenophorus isolepis*



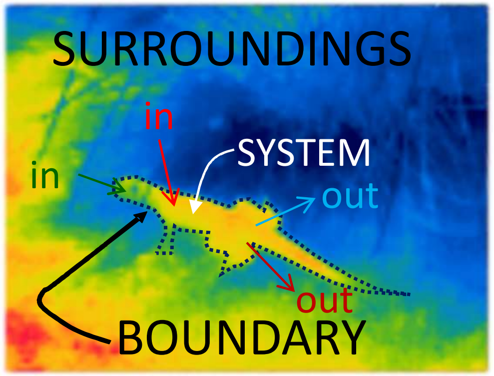


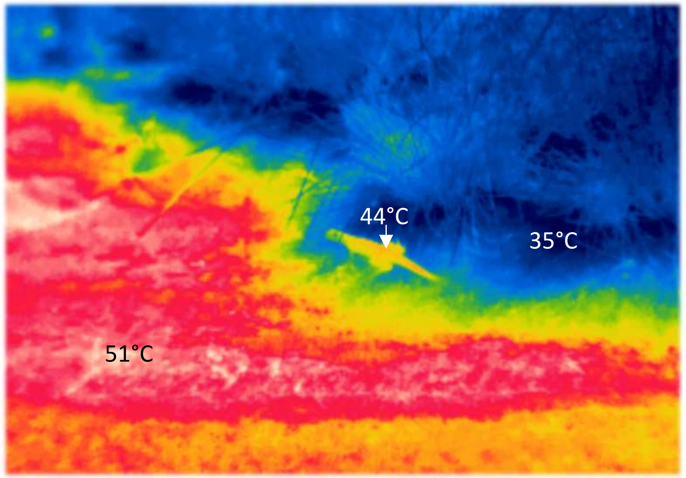


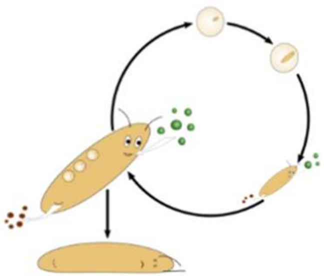
Thermodynamic basis to the niche

energy in =
energy out + energy stored

mass in =
mass out + mass stored







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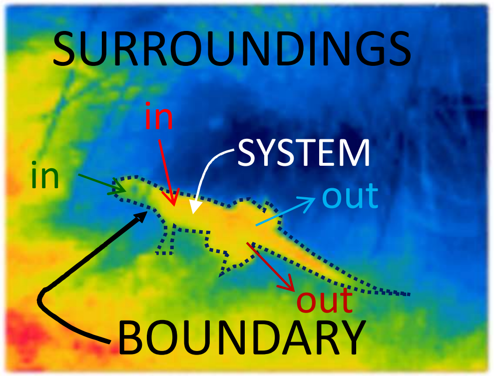

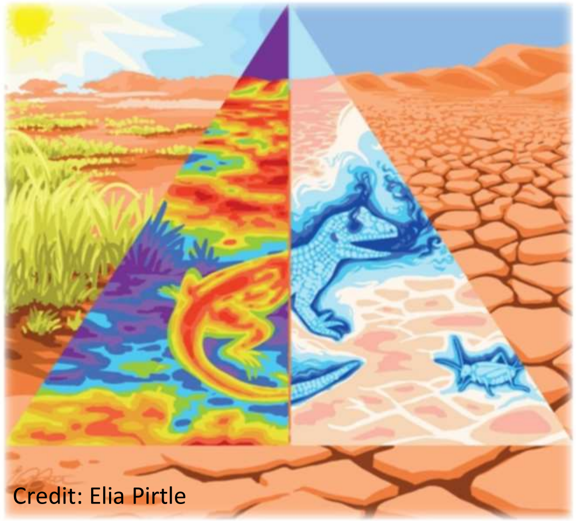

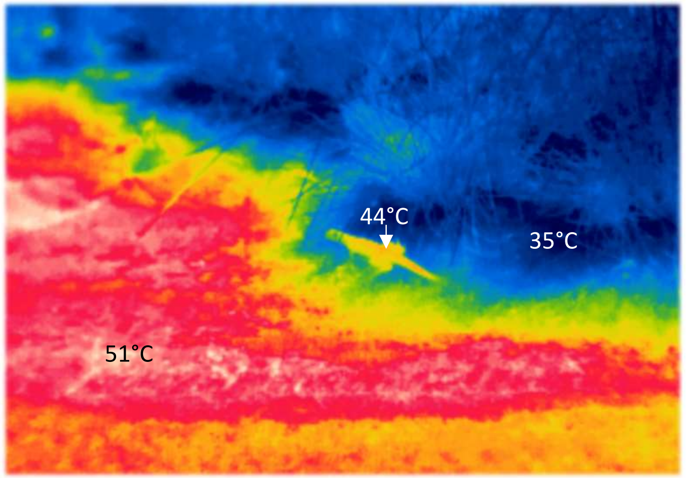

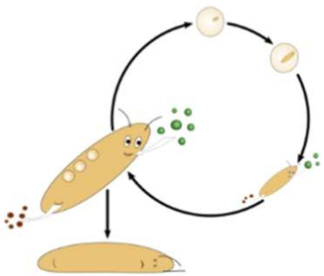

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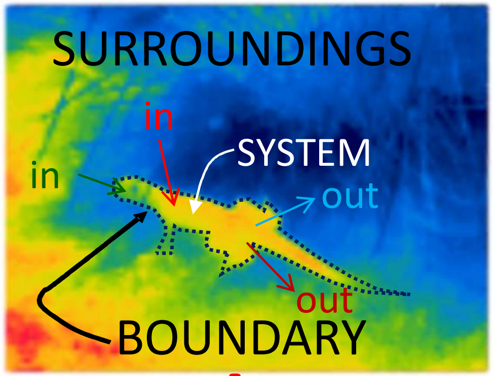
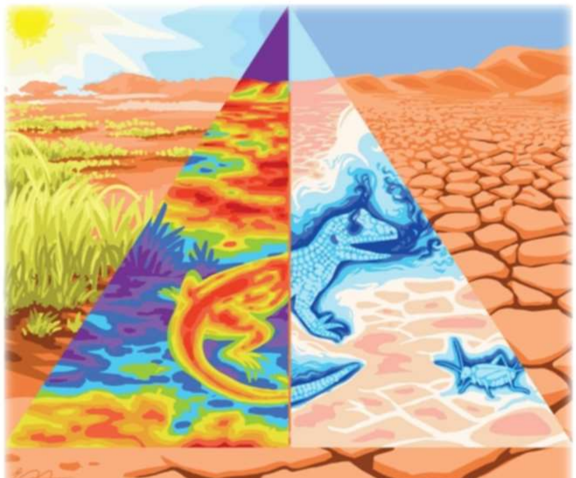
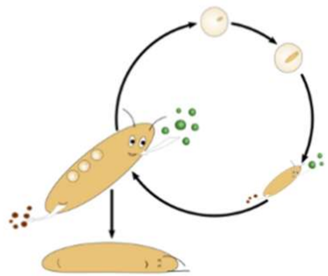




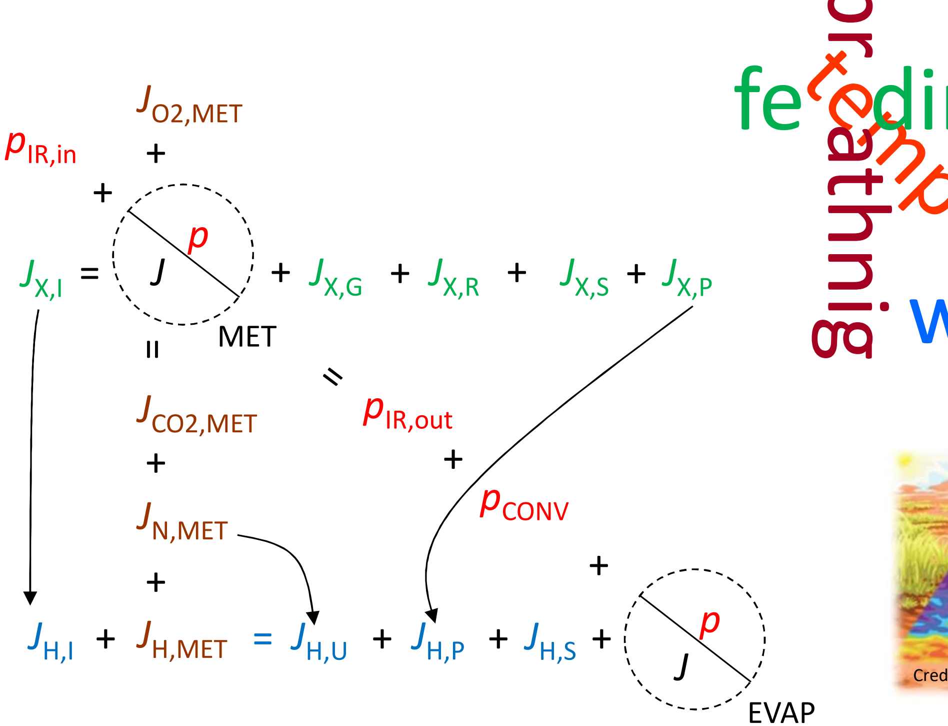
Credit: Elia Pirtle

temperature
feeding
breathing
water
water
feeding
breathing
temperature



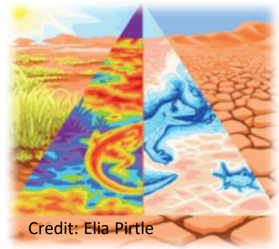
Thermodynamic basis to the niche

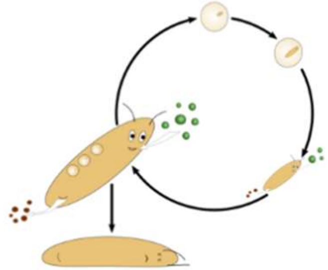
p = heat flux
J = mass flux
X = food
H = water
I = ingested
P = product (faeces)
U = urinated
G = growth
R = reproduction
S = stored
O_2 = oxygen
CO_2 = carbon dioxide
N = nitrogenous waste
MET = 'metabolism'
EVAP = evaporation
SOLAR = solar radiation
IR = infrared radiation
CONV = convection
COND =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



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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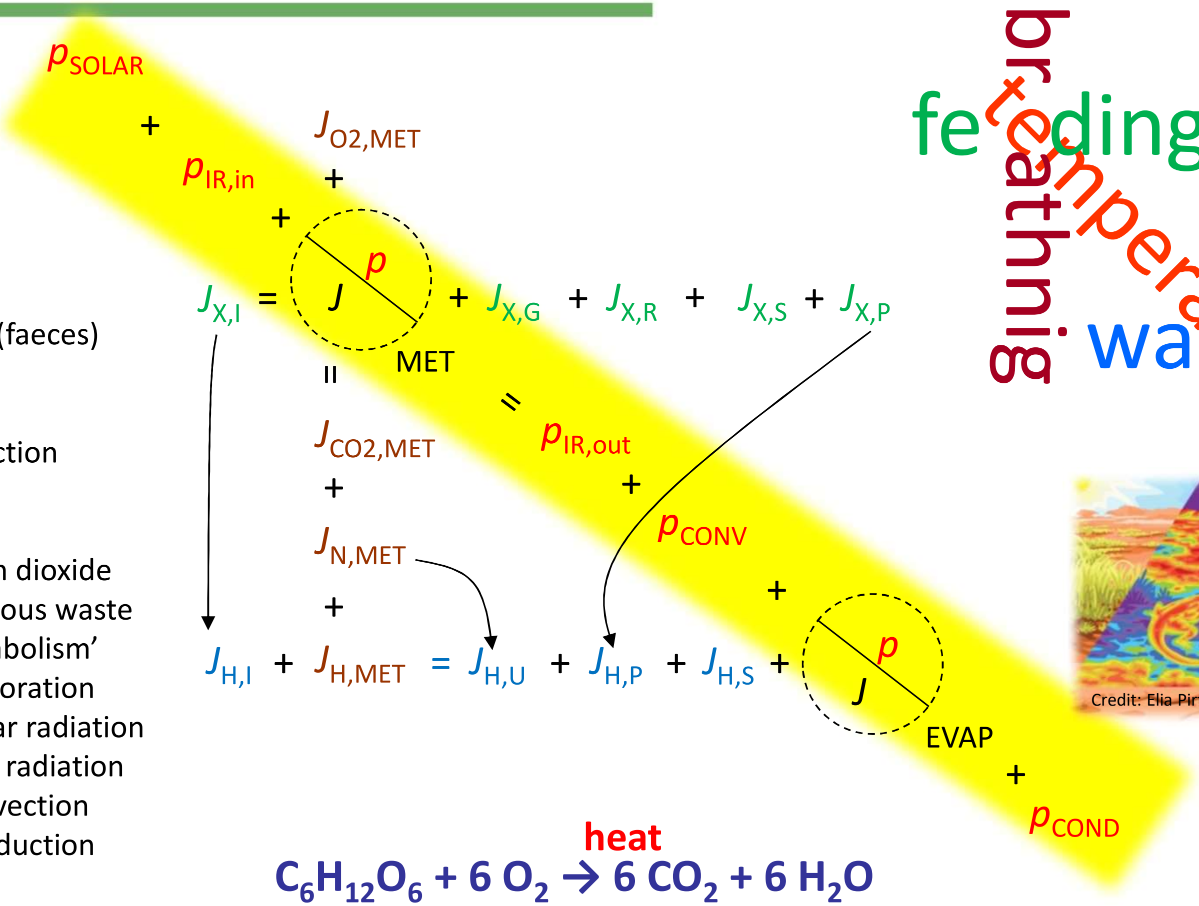
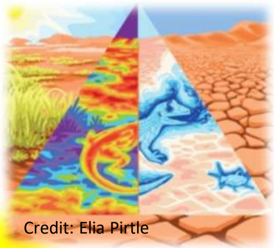
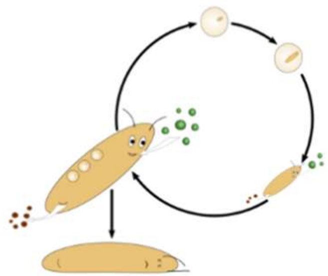


breathing
feeding
temperature
water





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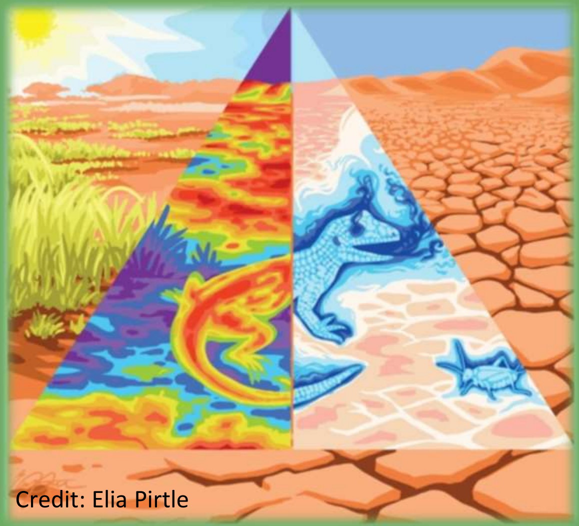
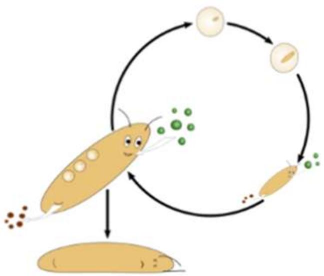
Kearney et al. **Functional Ecology (2013)** after Porter and Tracy (1983)



2. Biophysical Ecology

Computing a heat budget
Computing a water budget



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

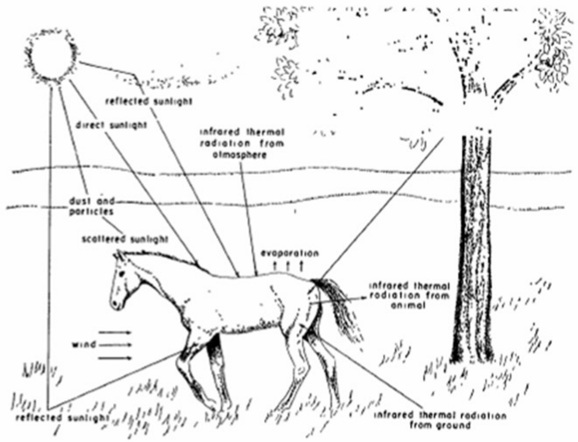
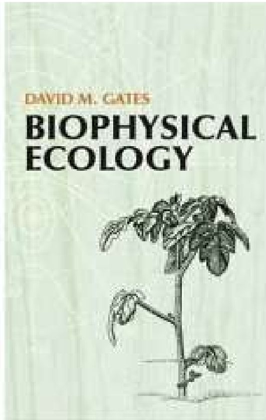
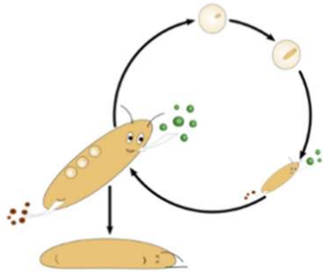
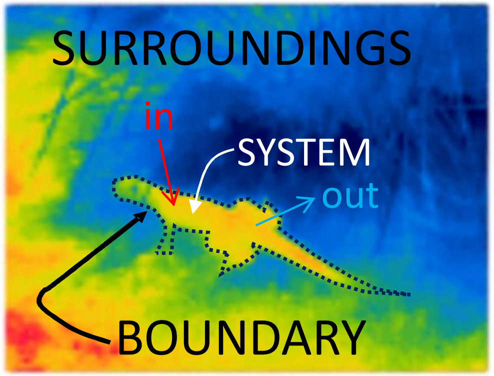


FIG. 1. Streams of energy between an animal and the environment.





Computing a heat budget

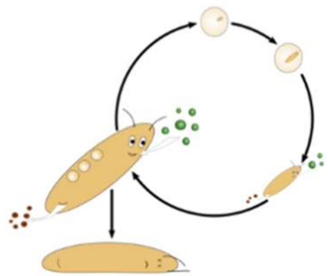


energy in = energy out

(Heat) Energy Balance of a Lizard

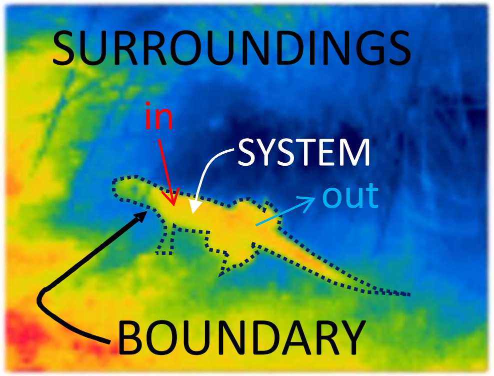
Metabolism (gained) + Solar (gained) + Infra-red (gained) =

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



Computing a heat budget

energy in = energy out



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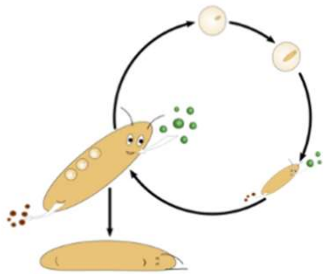
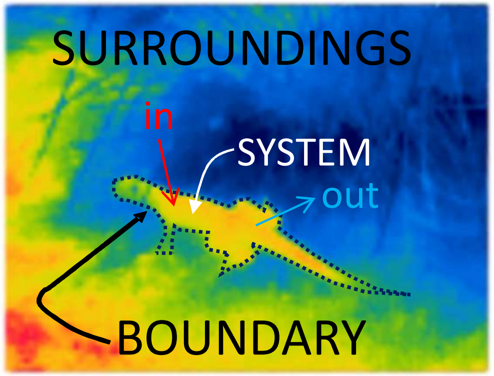


Computing a heat budget



energy in = energy out

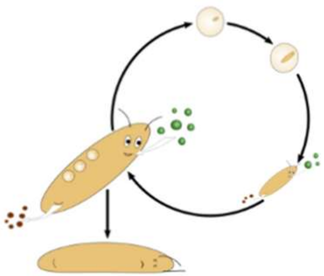
(Heat) Energy Balance of a Lizard

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

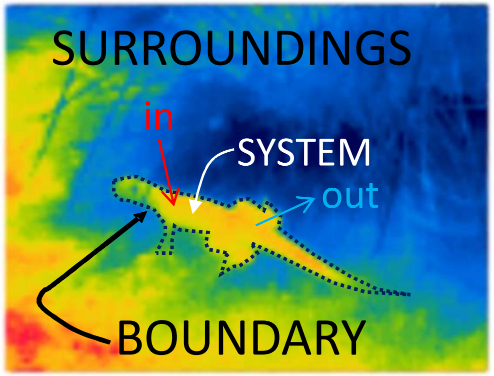
Infra-red (lost) + Convection (gained/lost)

$$\overbrace{A\alpha Q_{sol} + AQ_{IR}}^{\text{radiation gain}} =$$

$$\underbrace{A\varepsilon\sigma[T_b + 273.15]^4}_{\text{infra-red radiation lost}} + \overbrace{Ah_c\,[T_b - T_a]}^{\text{convection}}$$



Computing a heat budget



energy in = energy out

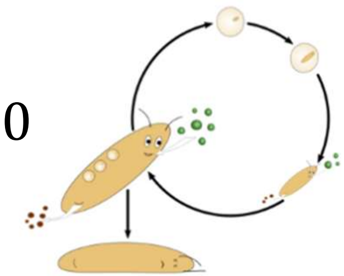
(Heat) Energy Balance of a Lizard

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

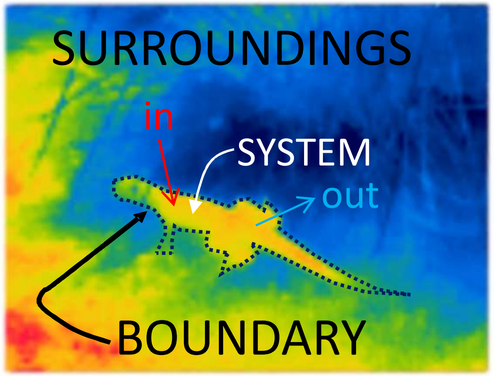
Infra-red (lost) + Convection (gained/lost)

radiation gain; convection; infra-red radiation lost

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



Computing a heat budget



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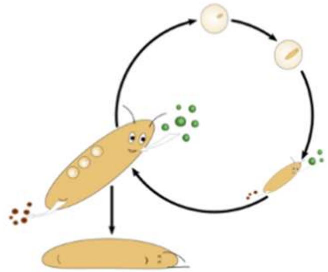
Infra-red (lost) + Convection (gained/lost)

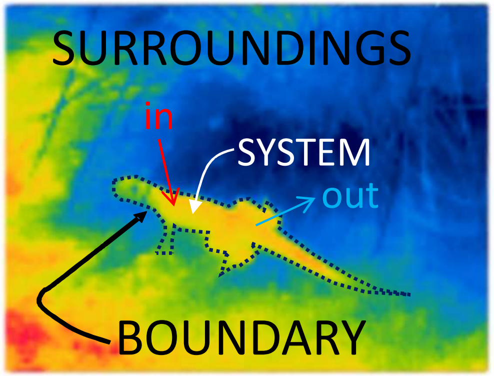
radiation gain; convection

$$\alpha Q_{sol} + Q_{IR} - \varepsilon\sigma[T_b + 273.15]^4 - h_c\,[T_b - T_a] = 0$$

infra-red radiation lost



Computing a heat budget



energy in = energy out

(Heat) Energy Balance of a Lizard

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

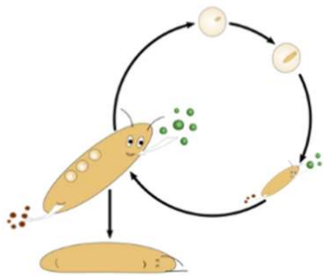
Infra-red (lost) + Convection (gained/lost)

radiation gain

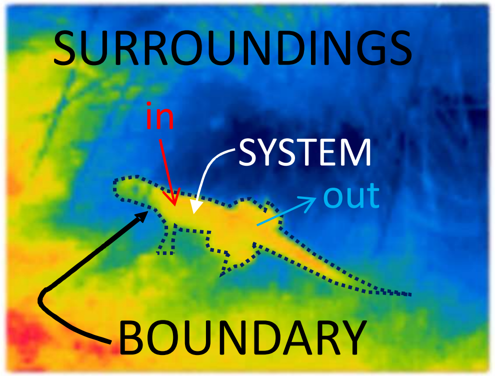
convection

$$Q_a - \varepsilon\sigma[T_b + 273.15]^4 - h_c\,[T_b - T_a] = 0$$

infra-red radiation lost



Computing a heat budget



energy in = energy out

(Heat) Energy Balance of a Lizard

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

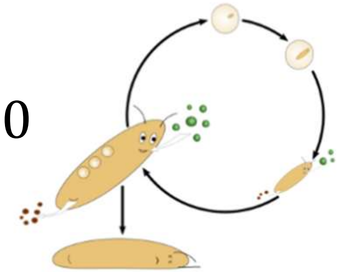
Infra-red (lost) + Convection (gained/lost)

radiation gain

convection

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

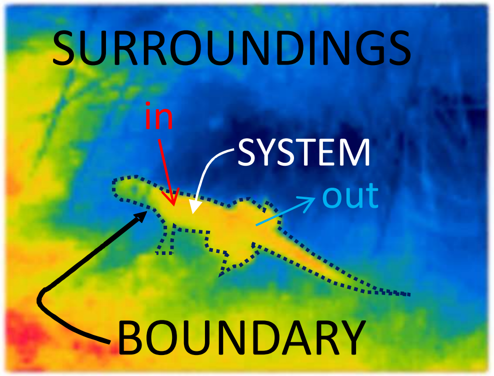
infra-red radiation lost



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

wind speed V,
organism size D

Computing a heat budget



energy in = energy out

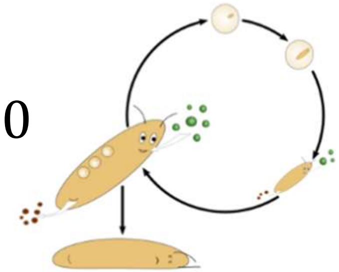
body temperature T_b (°C)
air temperature T_a (°C)
radiation absorbed Q_a (W/m^2)
wind speed V (m/s)
organism size D (m)
emissivity ε (-)
Stefan-Boltzmann constant
σ (W/m^2·K^4)

(Heat) Energy Balance of a Lizard

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

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

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



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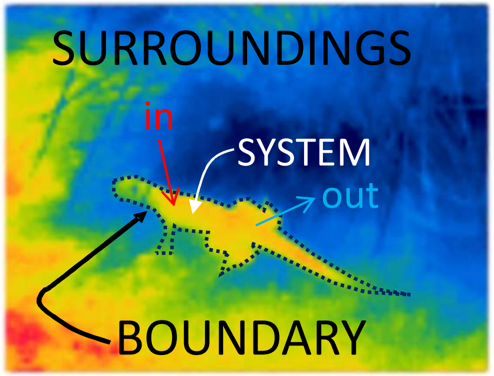


What would the body temperature be if …?

Diameter = 0.015 m

Wind speed = 2.0 m/s

Air temperature = 20 ºC

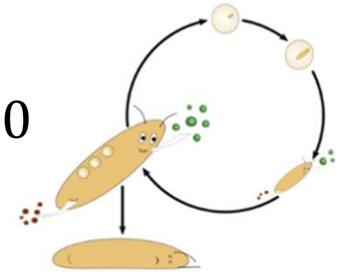
Radiation = 700 W/m2

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
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- X = food
- H = water
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- P = product (faeces)
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- R = reproduction
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- N = nitrogenous waste
- MET = 'metabolism'
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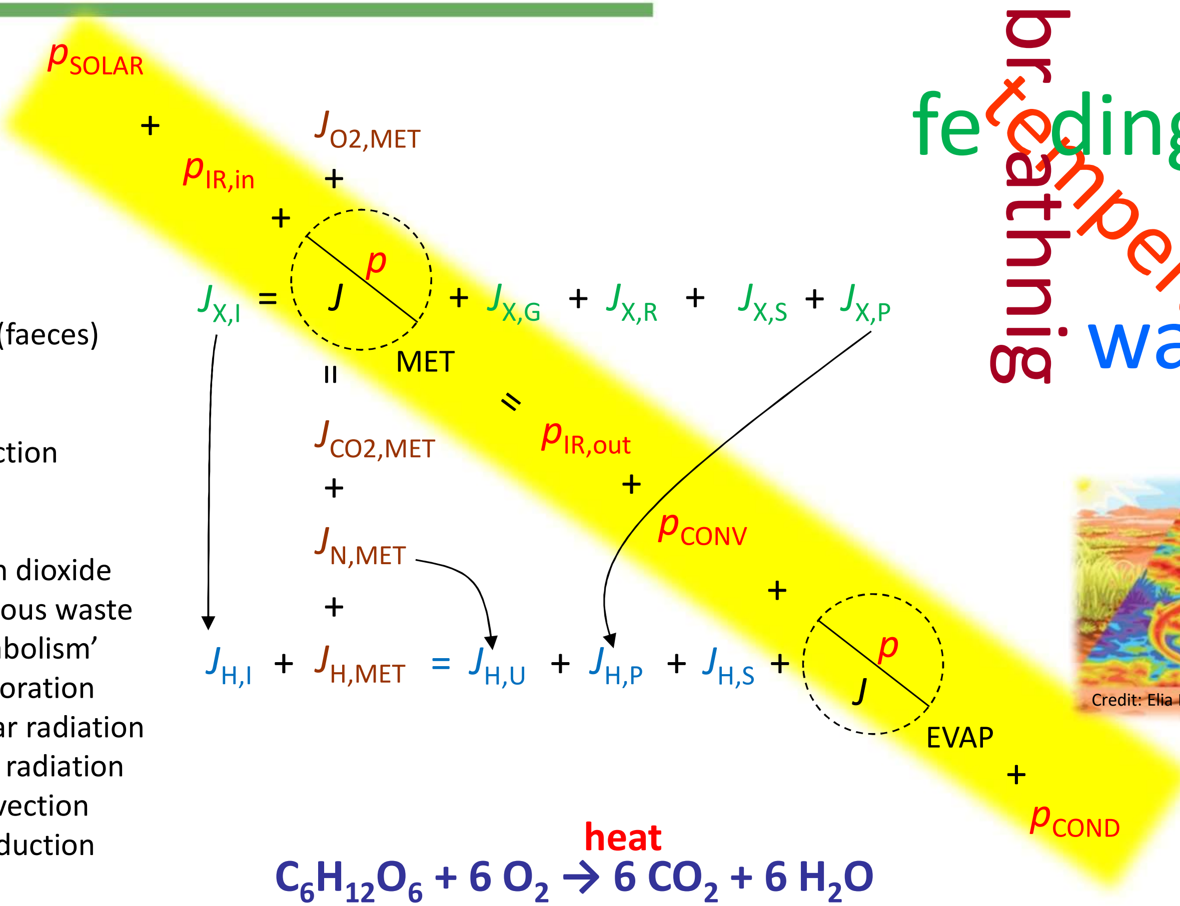
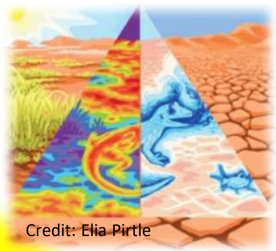
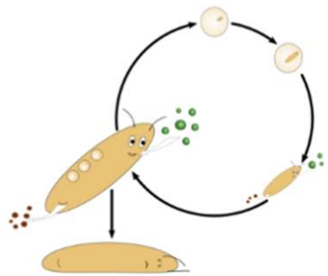


$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$





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

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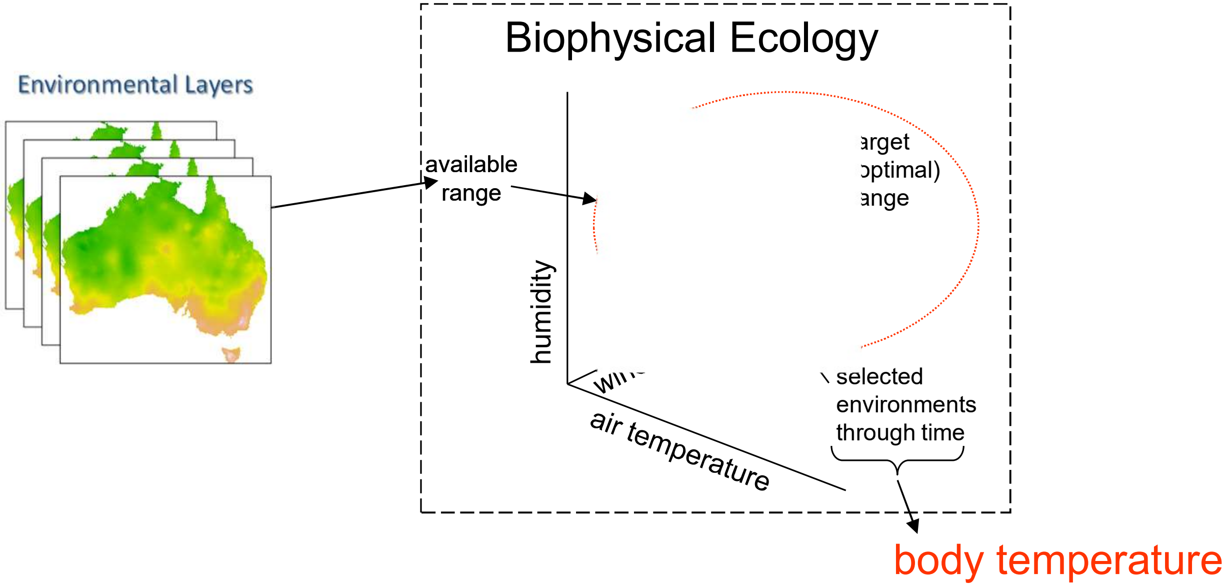

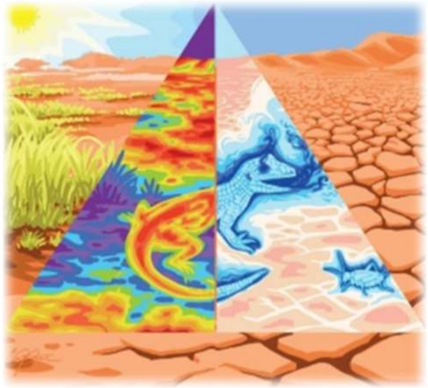

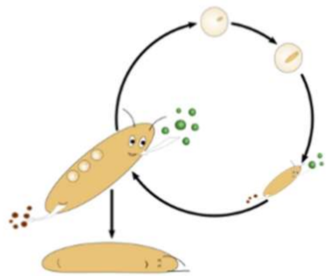

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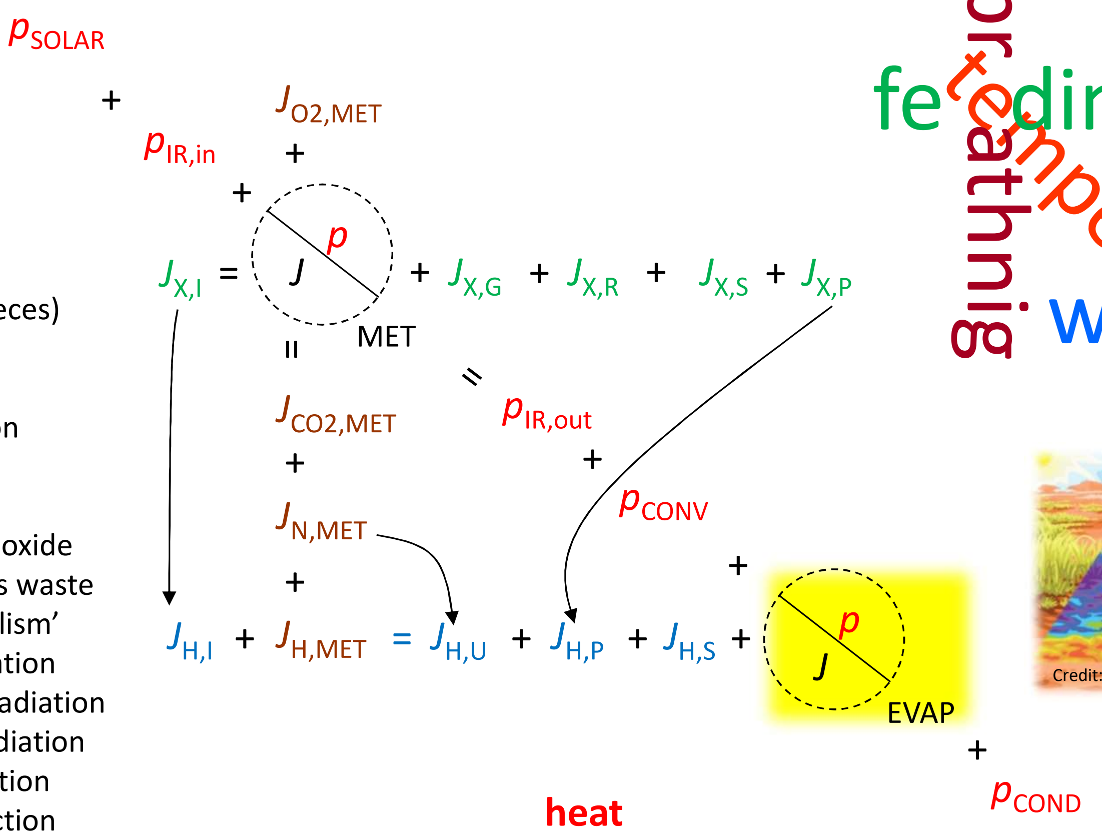
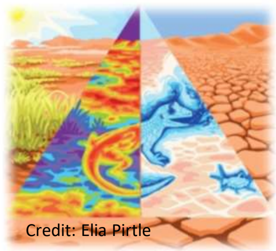
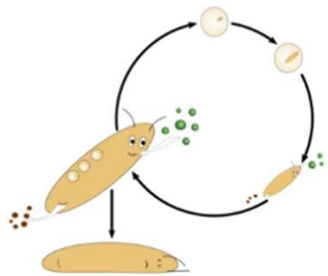


feeding
breathing
temperature
water





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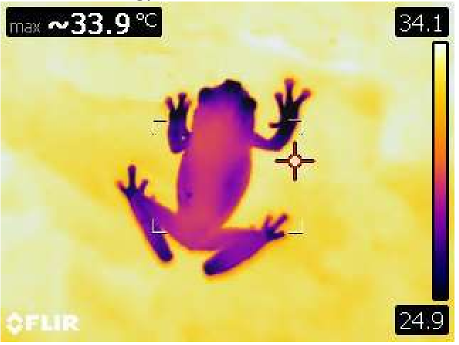
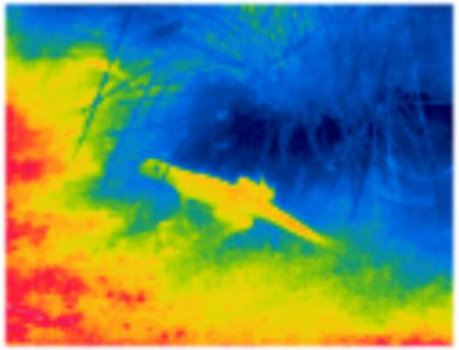
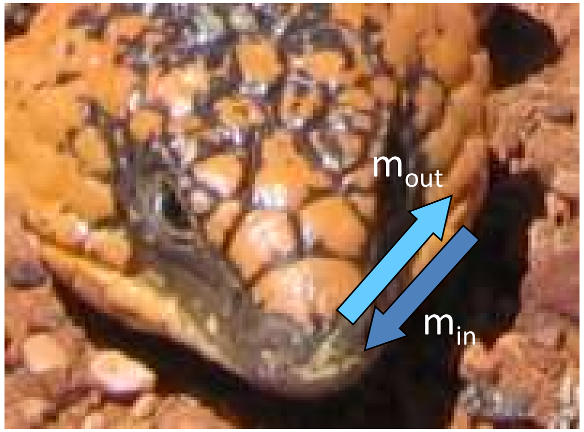
Computing a water budget

Greer 1989 Biology and Evolution of Australian Lizards







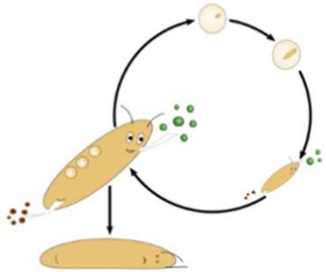
area wet, m²

latent heat of vaporisation,

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

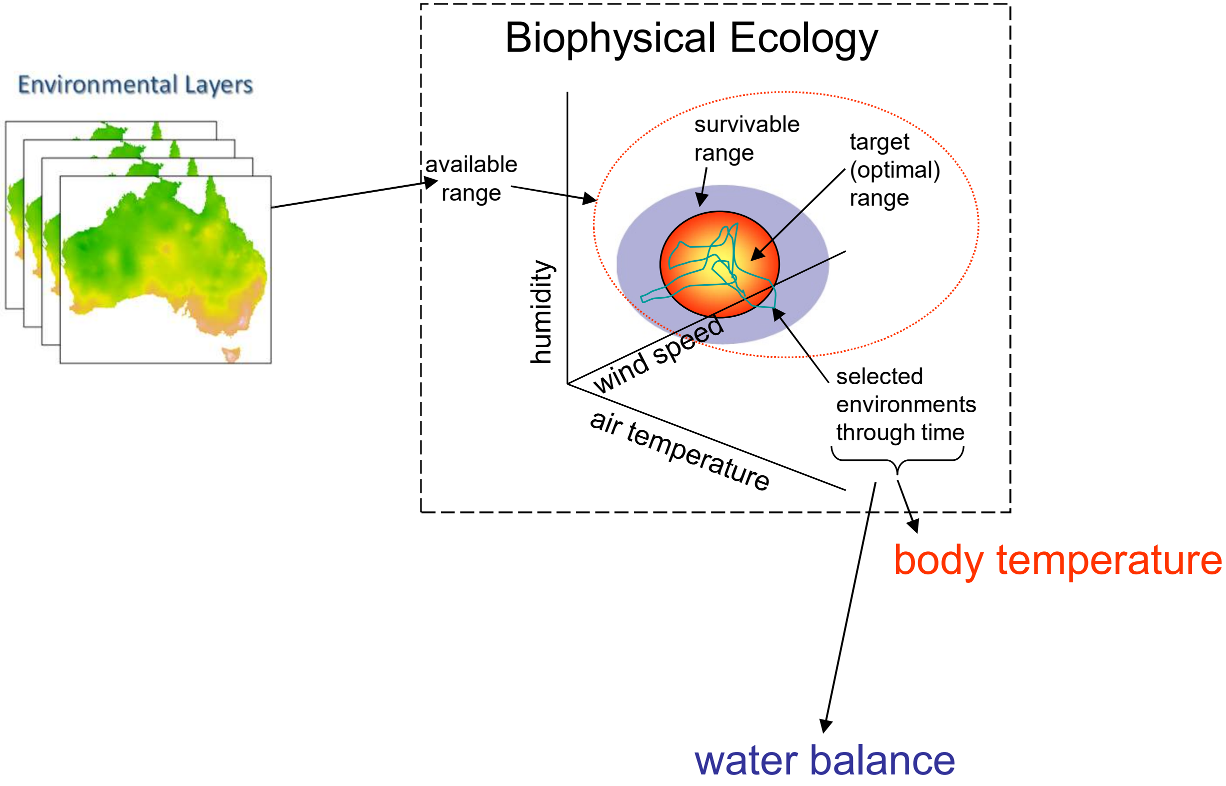
mass transfer coefficient

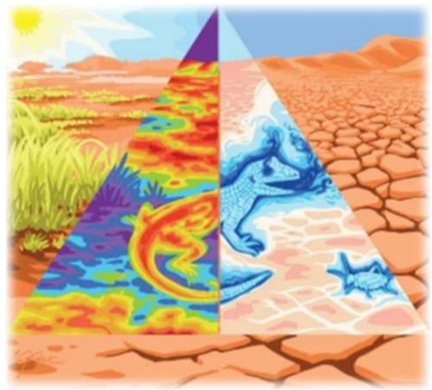
vapor density,

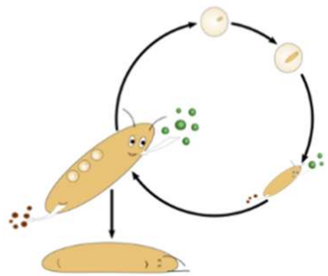


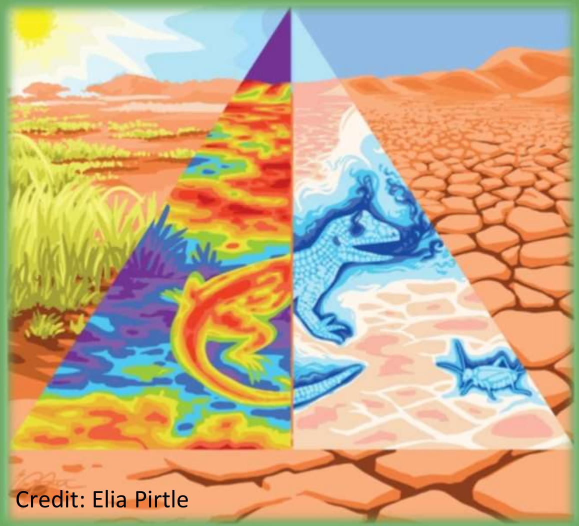
$$Q_{evap,resp} = \lambda(m_{out,resp} - m_{in,resp})$$

Thermodynamic basis to the niche



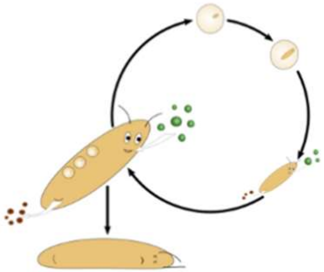





Credit: Elia Pirtle

3. Connecting to DEB theory

- Inferring climatic constraints
- Incorporating nutritional constraints



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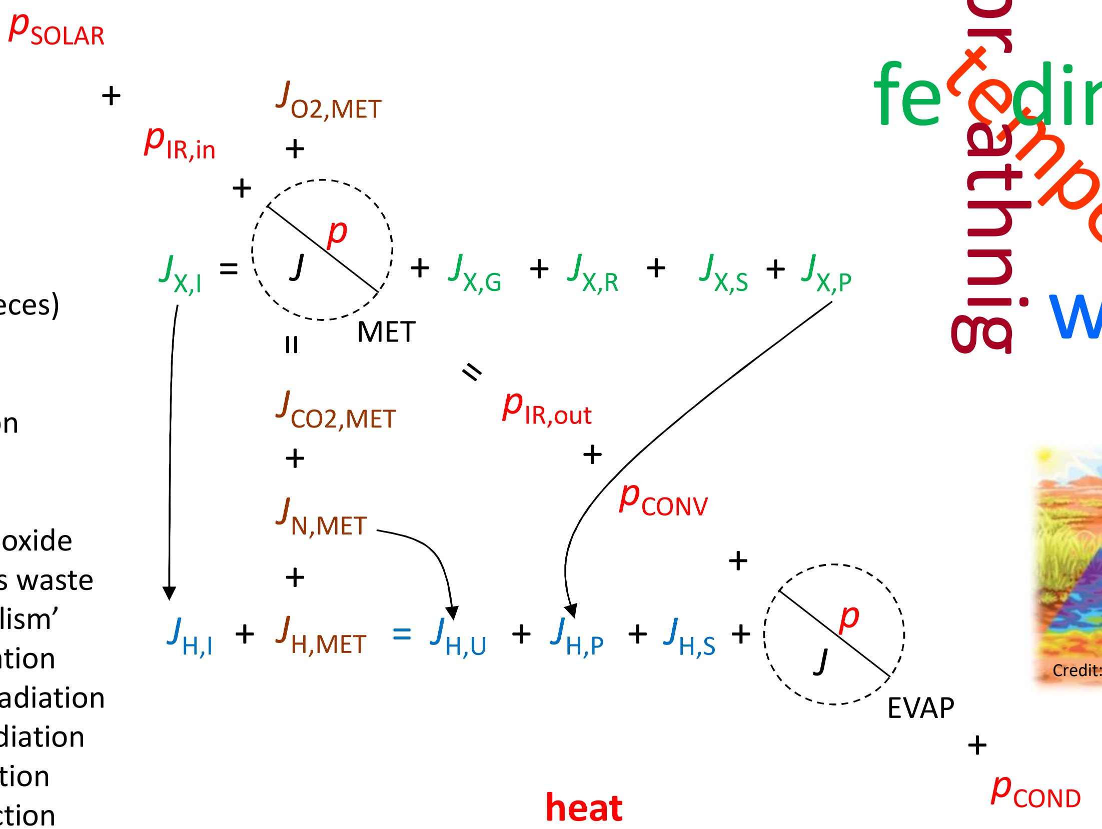
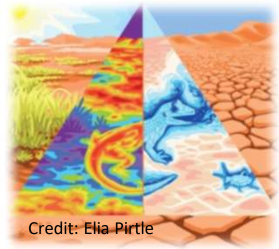
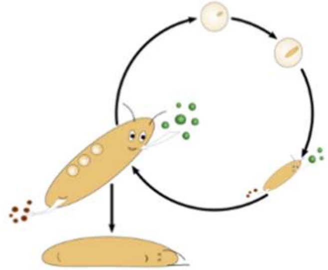


breathing feeding temperature water





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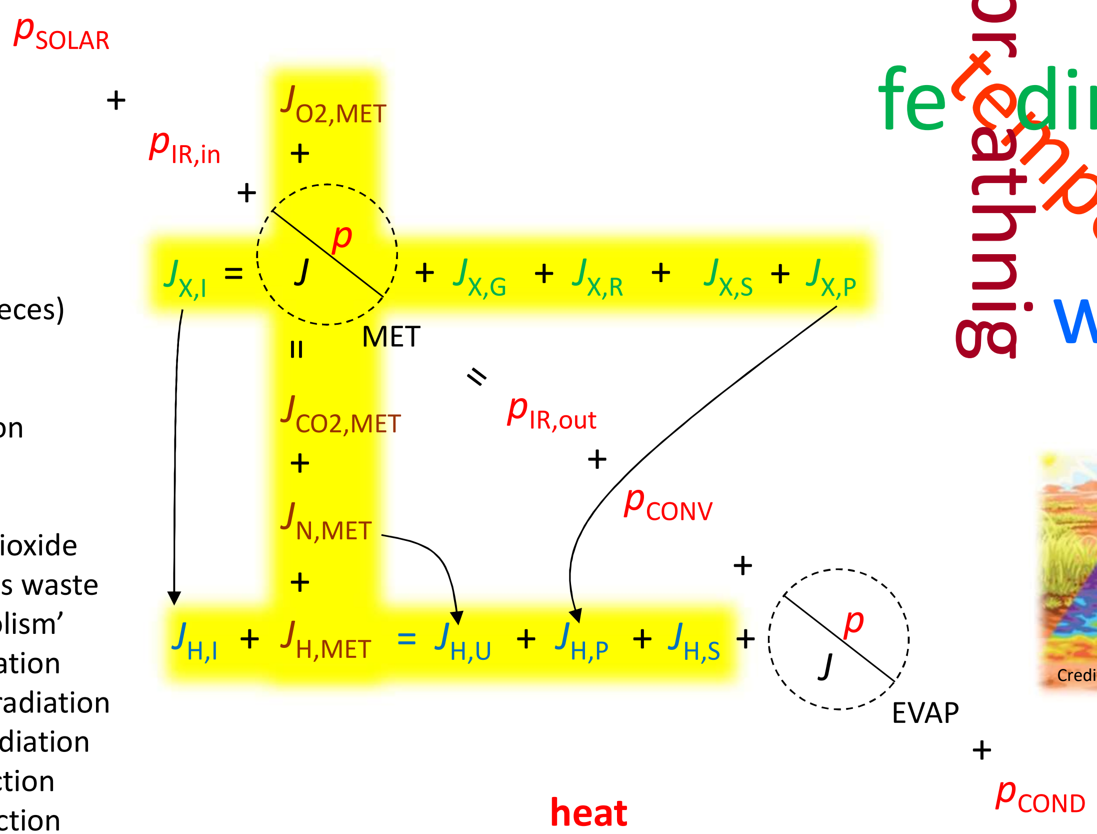

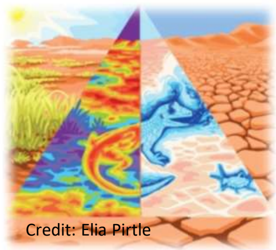

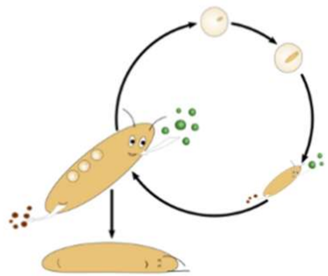

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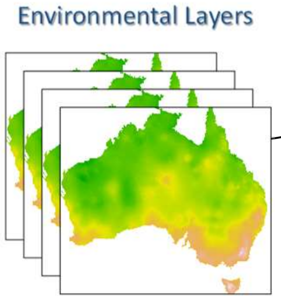

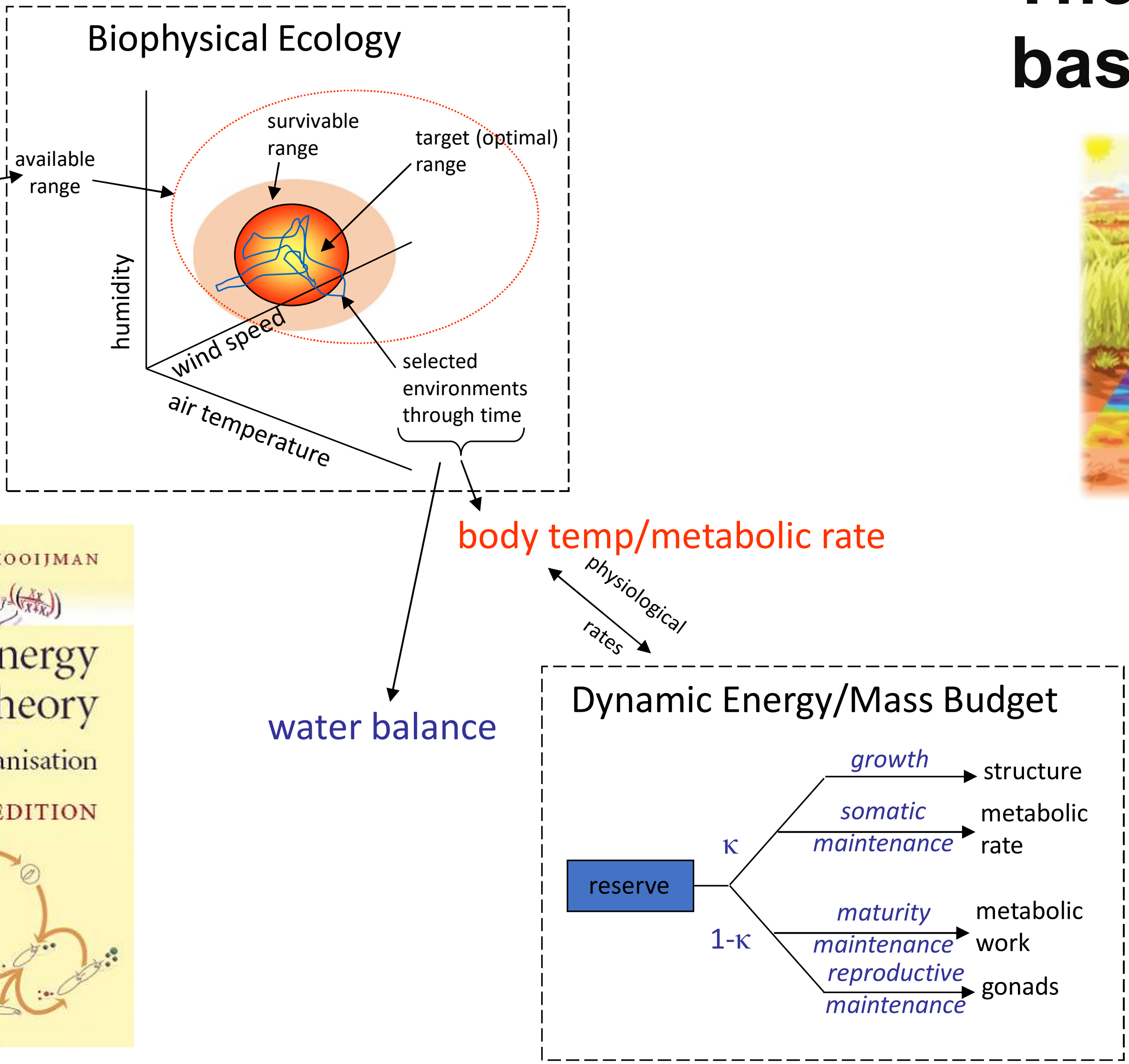

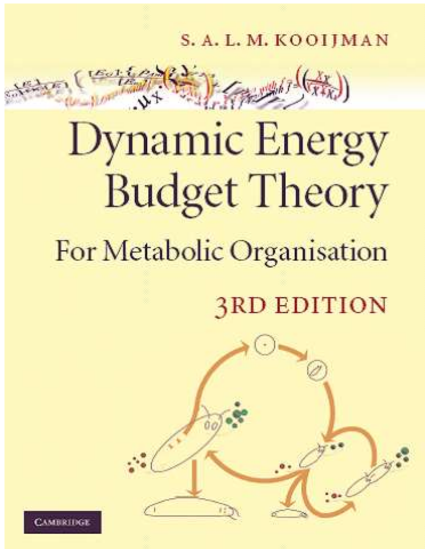

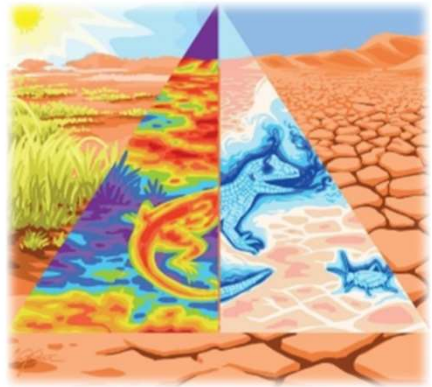

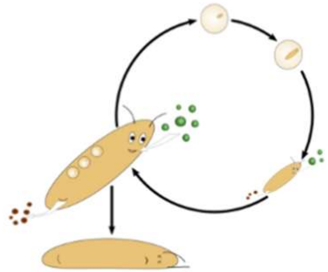

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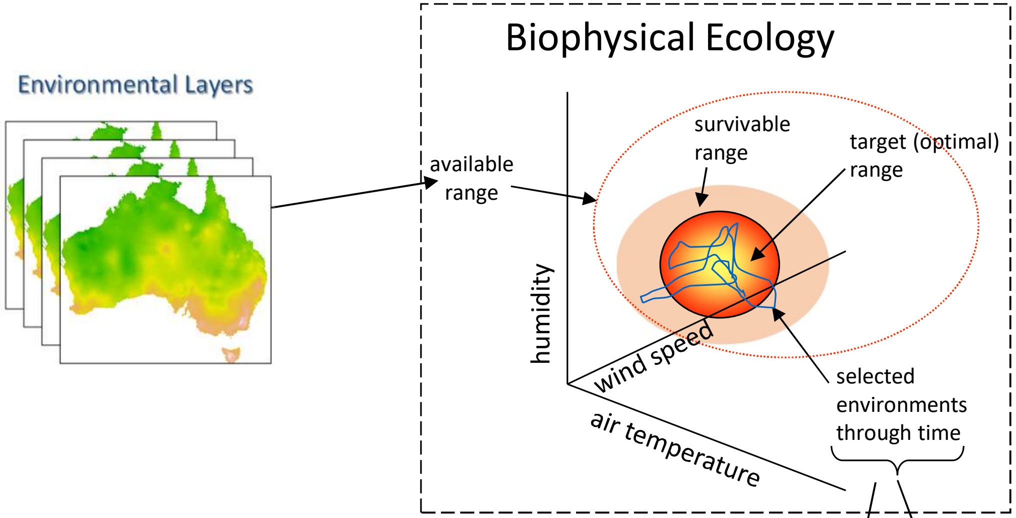
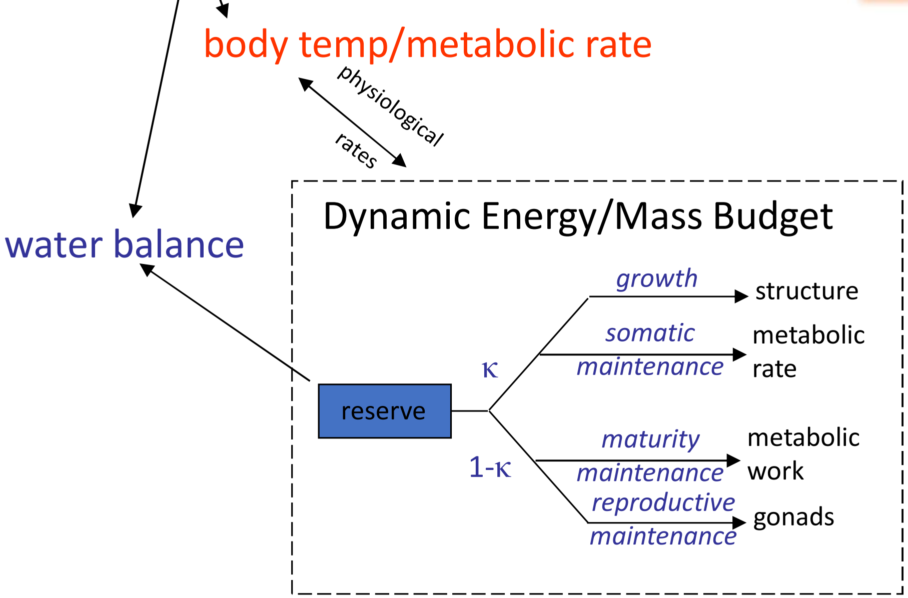
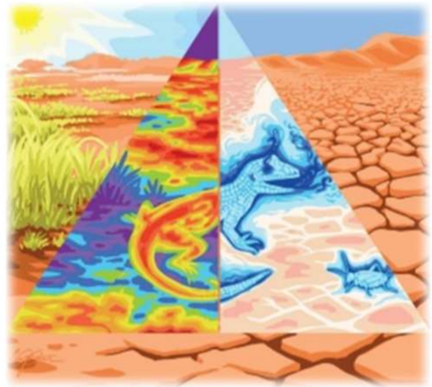
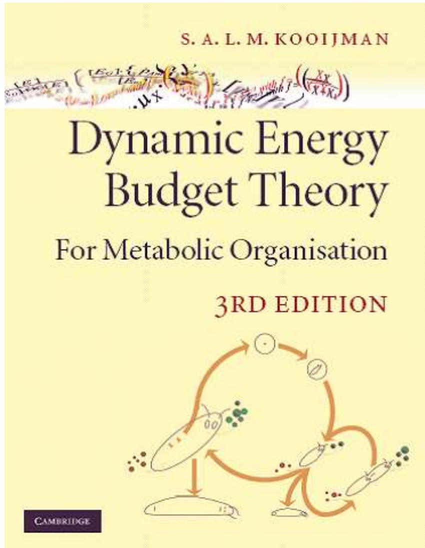
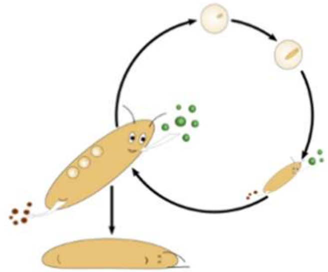




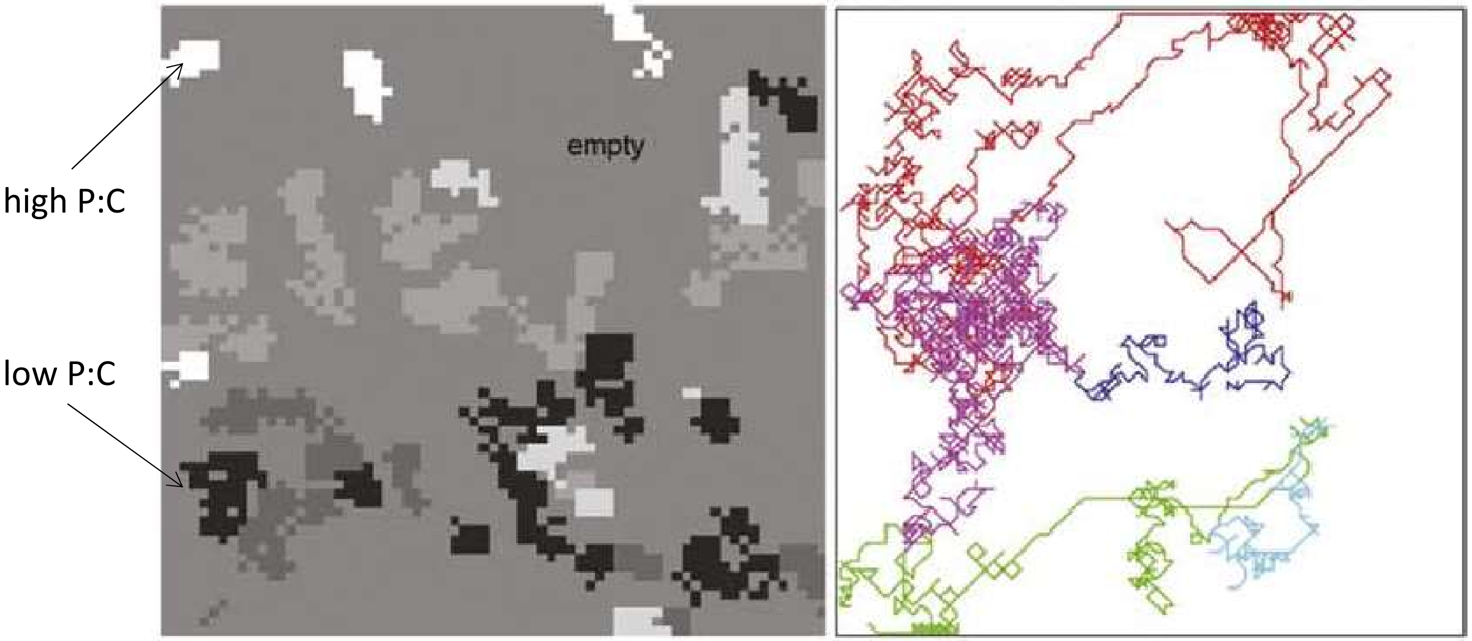


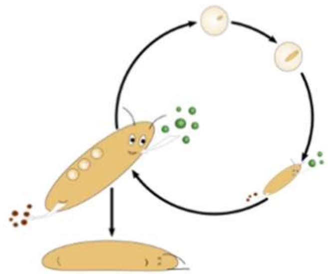




Incorporating nutritional constraints

Nutritional Landscape

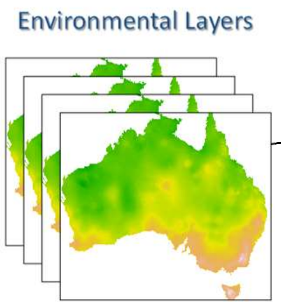


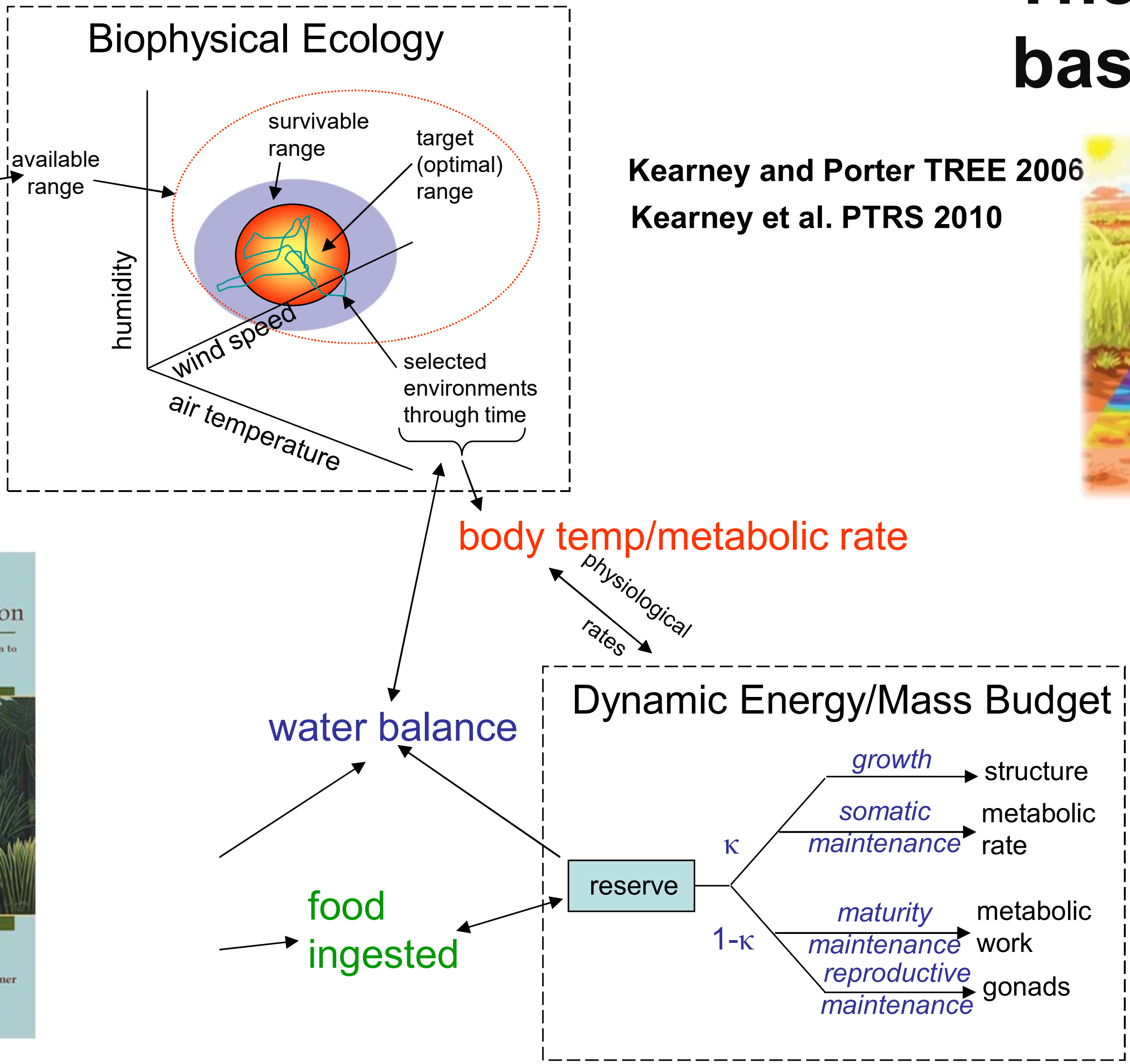


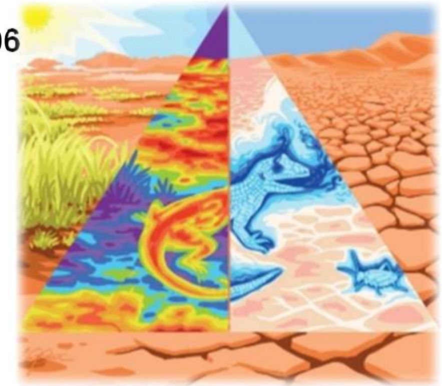
Thermodynamic basis to the niche

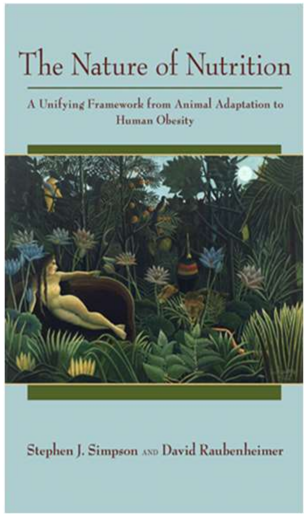
Kearney and Porter TREE 2006

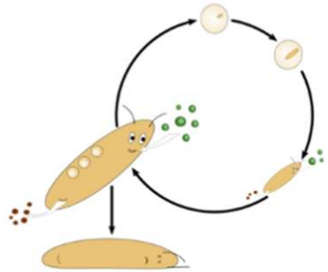
Kearney et al. PTRS 2010











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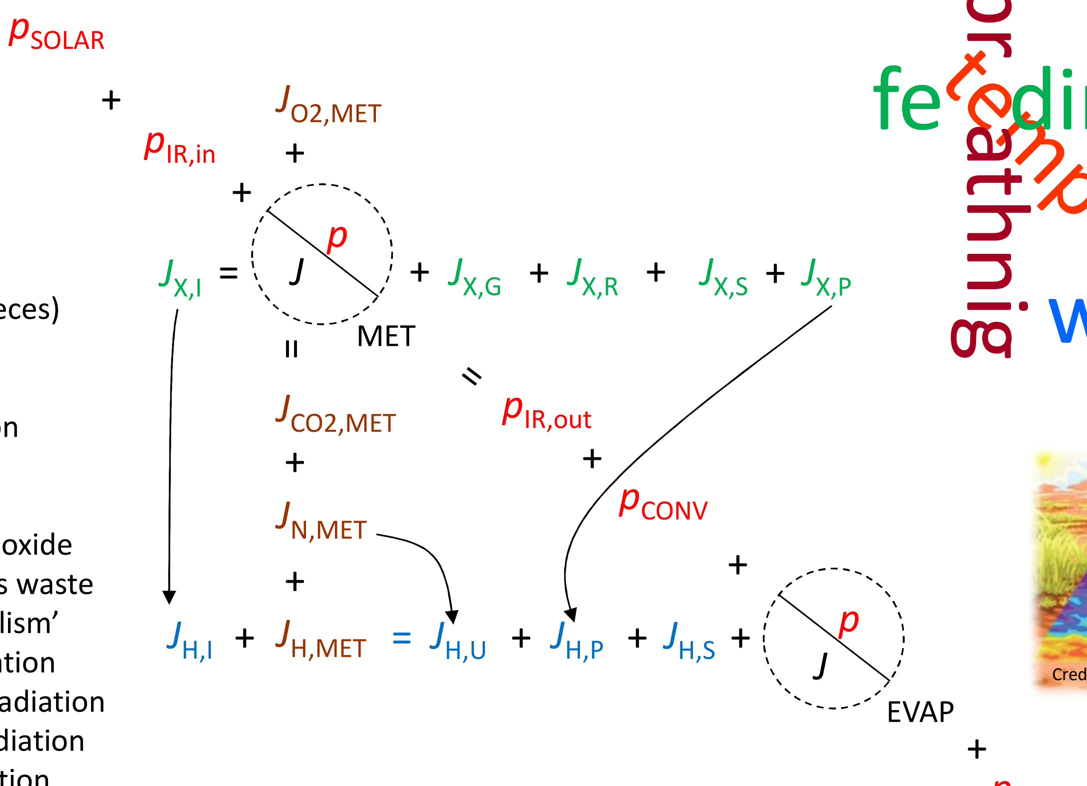
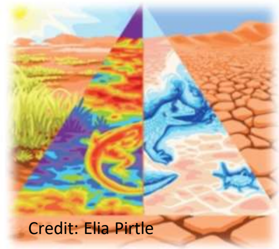
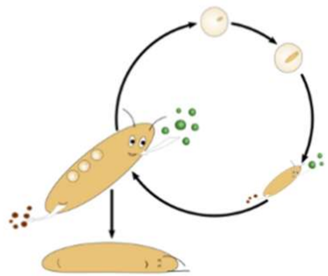


breathing
feeding
temperature
water





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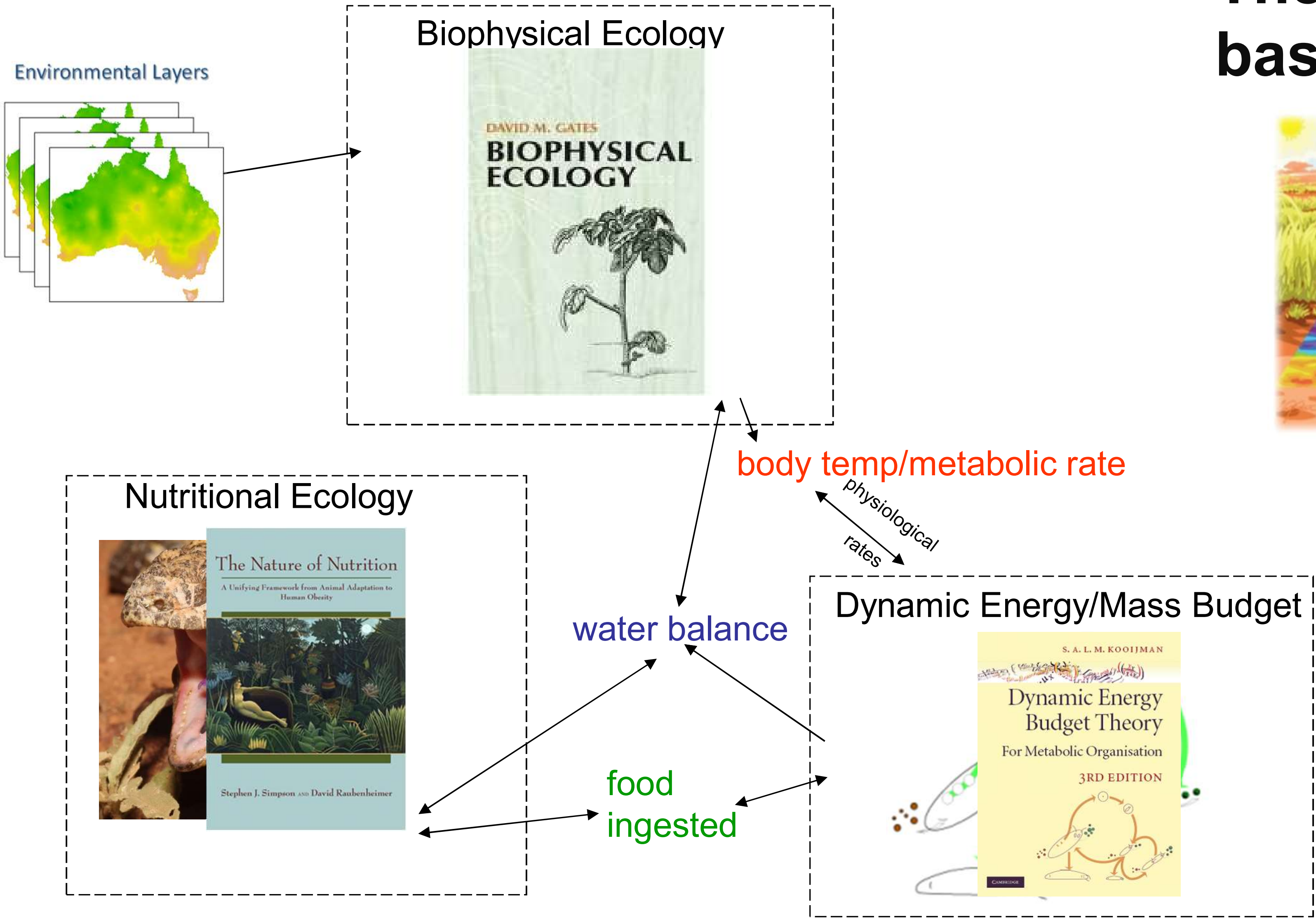
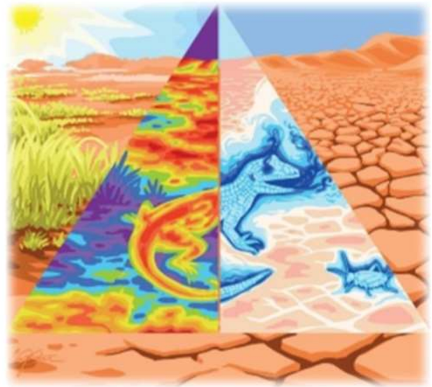
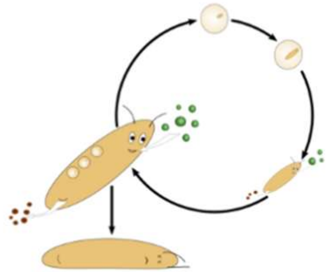
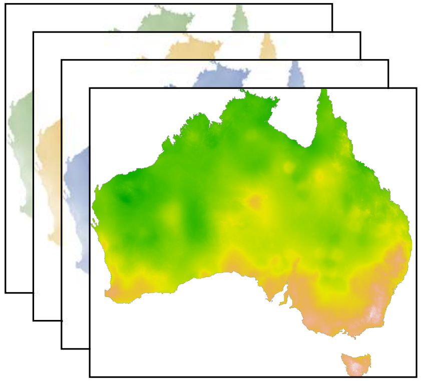






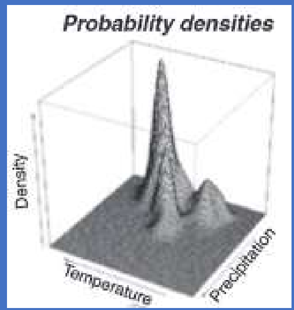
What is a mechanistic niche model?

Environmental Layers

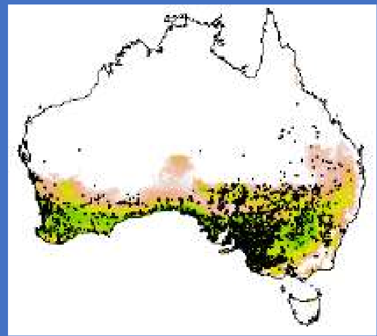


Correlative Model (process implicit)

Maxent model



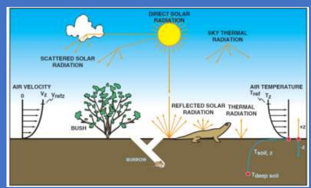
probability of occurrence



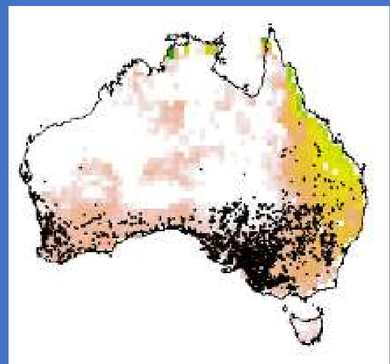
* starts with occurrence records

Mechanistic Model (process explicit)

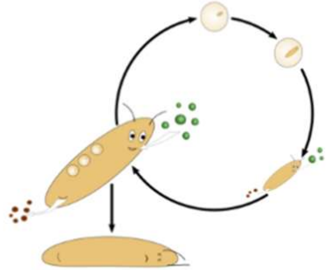
NicheMapR model

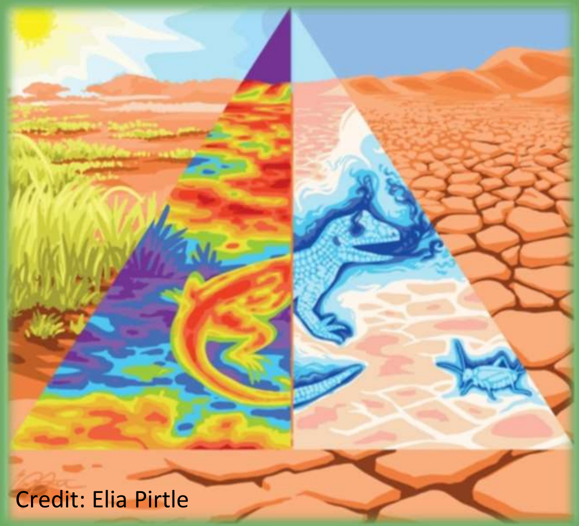


potential reproduction



* starts with functional traits

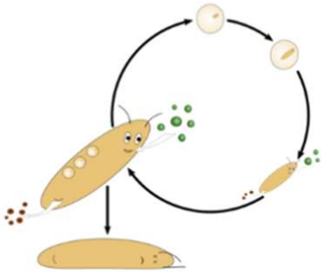




4.

Functional traits and mechanistic niche models

- Dynamical systems models
- Theoretical types of functional traits



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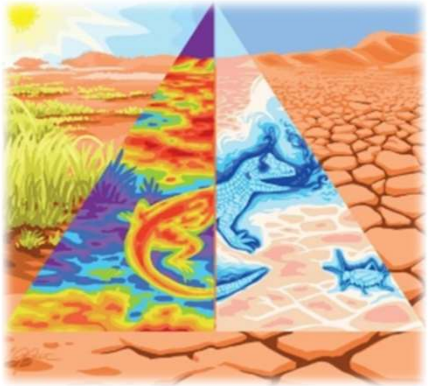
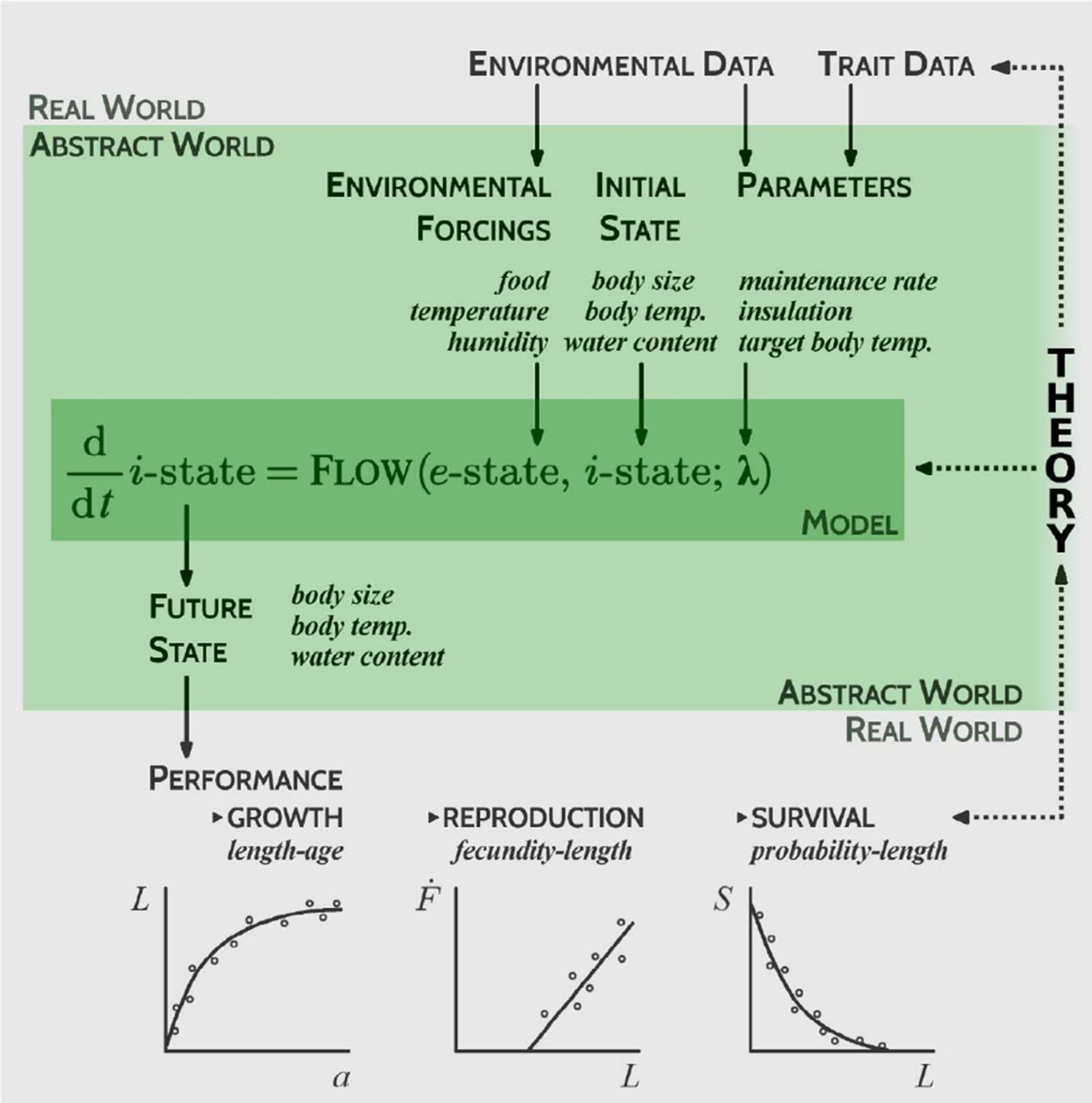
Functional Ecology BRITISH ECOLOGICAL SOCIETY

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]

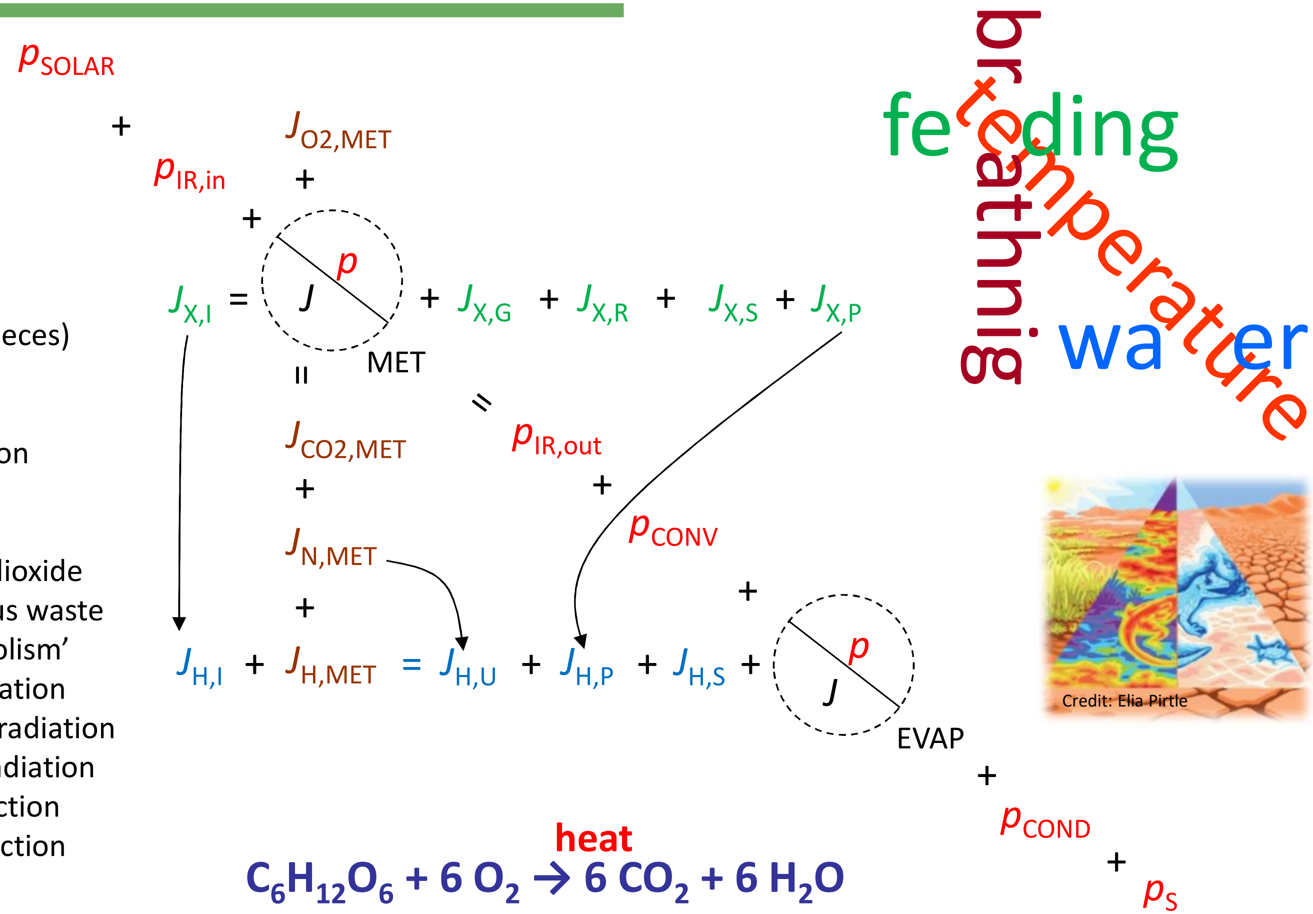




ENVIRONMENTAL DATA
TRAIT DATA
REAL WORLD
ABSTRACT WORLD
ENVIRONMENTAL FORCINGS
INITIAL STATE
PARAMETERS
food
temperature
humidity
body size
body temp.
water content
maintenance rate
insulation
target body temp.
THEORY
$\frac{\mathrm{d}}{\mathrm{d}t} i\text{-state} = \textsc{Flow}(e\text{-state},\ i\text{-state};\ \lambda)$
MODEL
FUTURE STATE
body size
body temp.
water content
ABSTRACT WORLD
REAL WORLD
PERFORMANCE
GROWTH
length-age
REPRODUCTION
fecundity-length
SURVIVAL
probability-length
L
a
$\dot{F}$
L
S
L

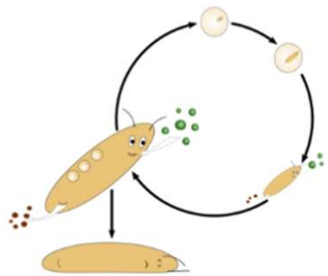
Thermodynamic basis to the niche

- 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

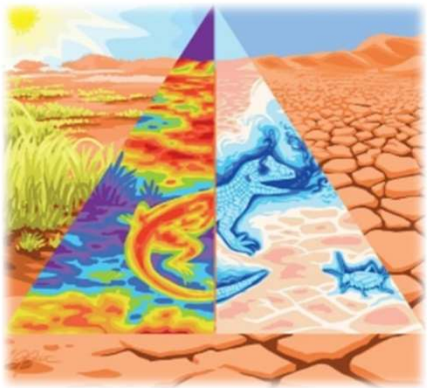


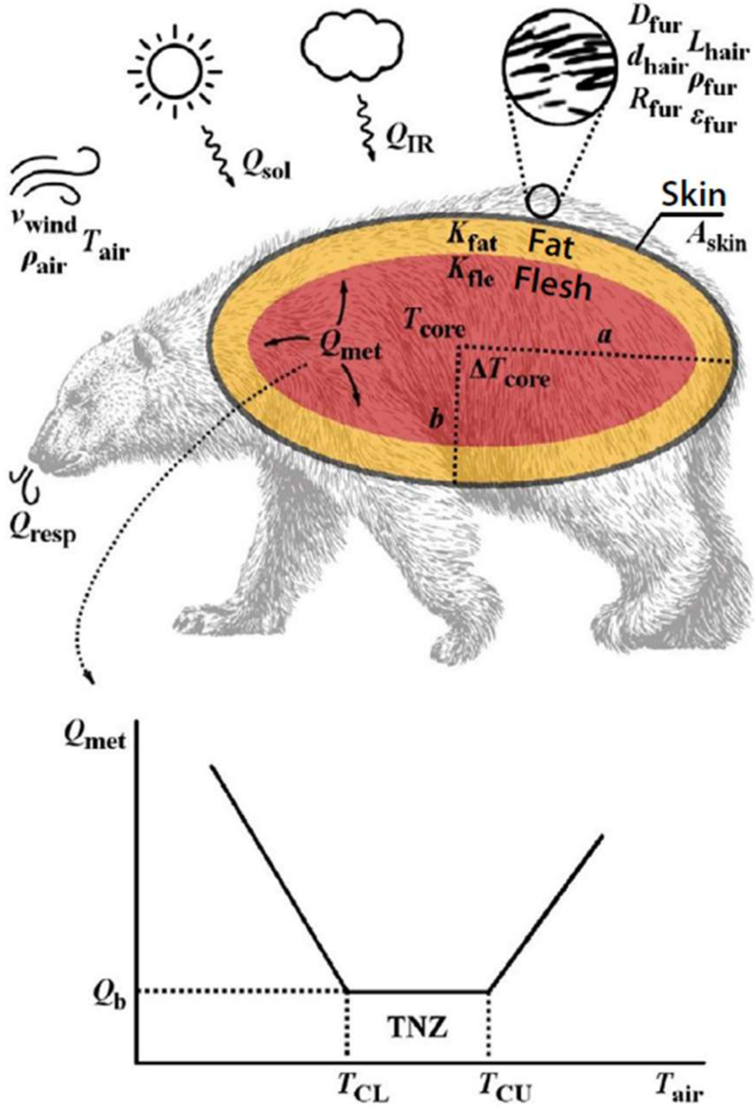
heat

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



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





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

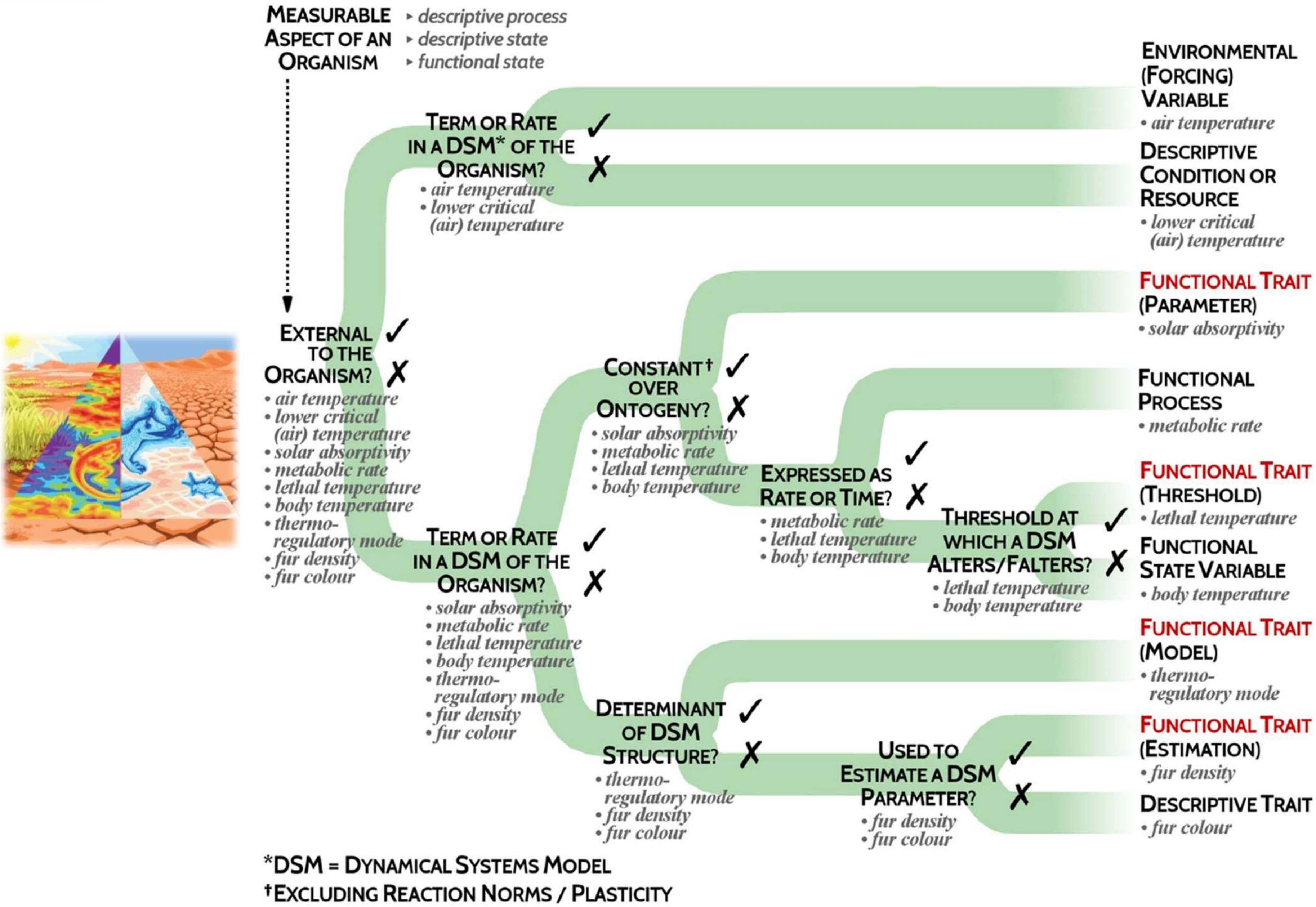
- Metabolic rate Q_{met}
- Respiration Q_{resp}

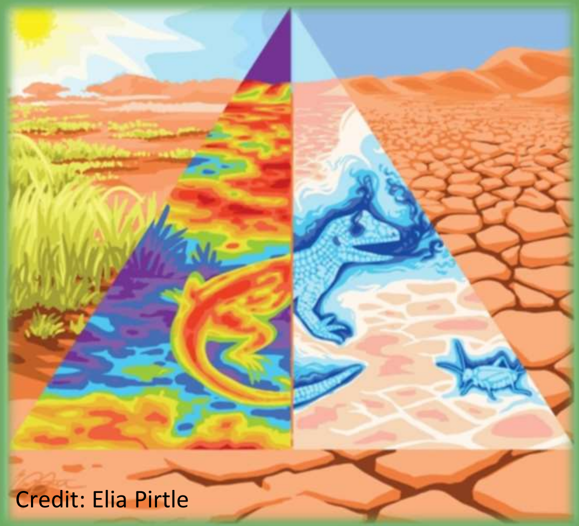
State variable

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

Other

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

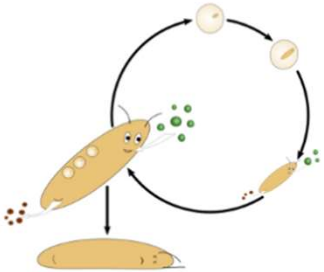

MEASURABLE ASPECT OF AN ORGANISM
▸ descriptive process
▸ descriptive state
▸ functional state
EXTERNAL TO THE ORGANISM? ✓ ✗
• air temperature
• lower critical (air) temperature
• solar absorptivity
• metabolic rate
• lethal temperature
• body temperature
• thermo-regulatory mode
• fur density
• fur colour
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



4.

Ding dong the niche is dead?

Criticism of the niche concept
Individuals to populations



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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
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H = water
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U = urinated
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S = stored
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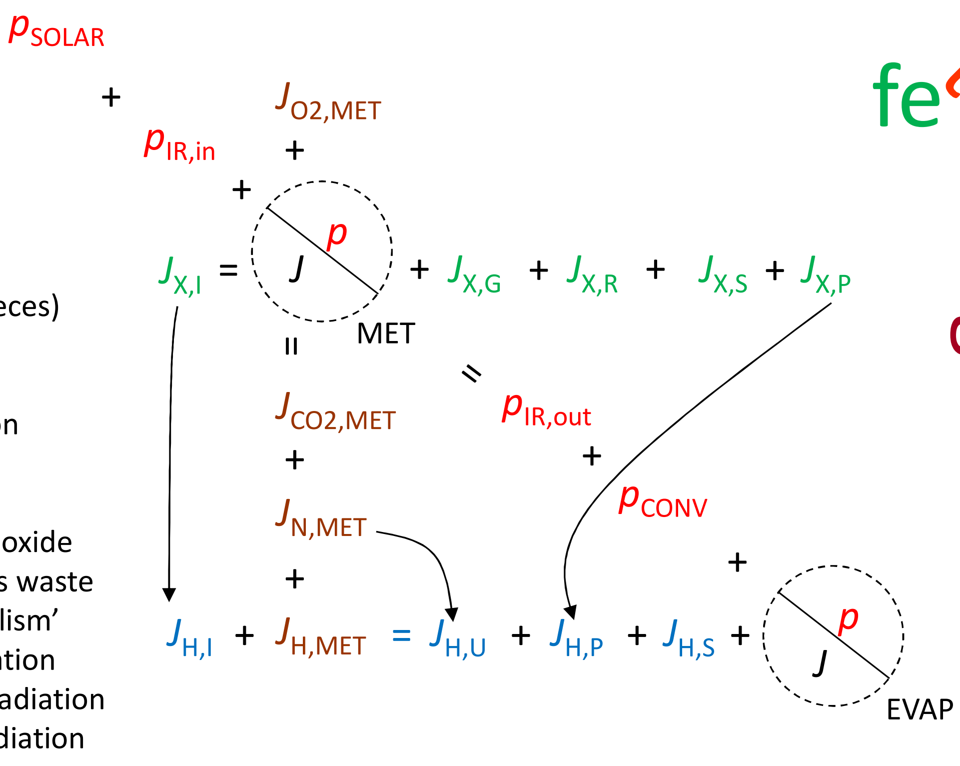

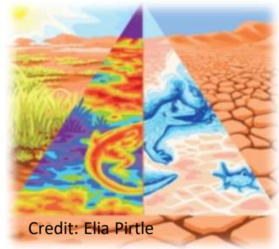

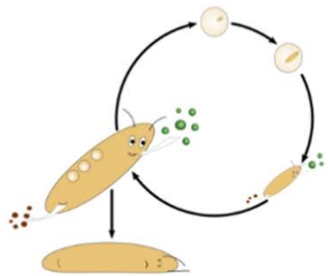

heat

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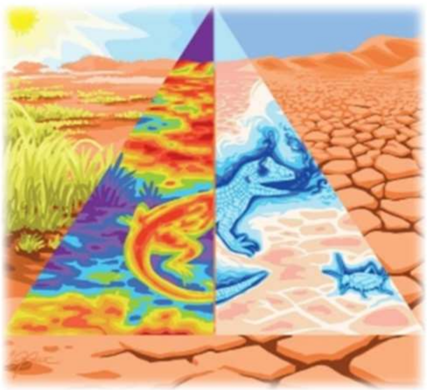
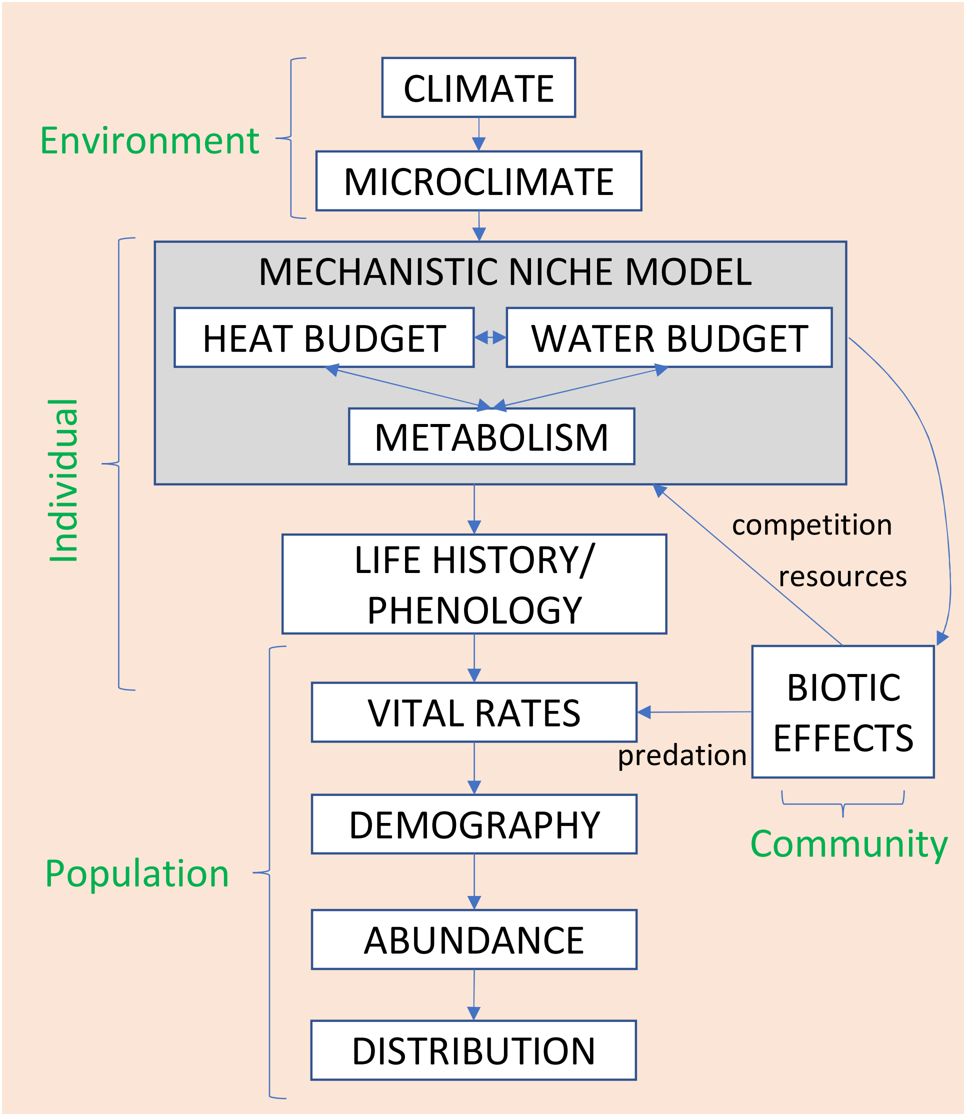
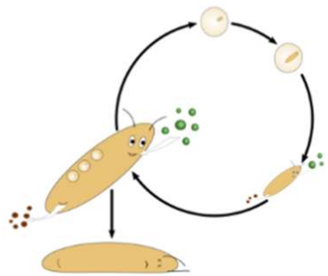




Environment
CLIMATE
MICROCLIMATE
Individual
MECHANISTIC NICHE MODEL
HEAT BUDGET
WATER BUDGET
METABOLISM
LIFE HISTORY/
PHENOLOGY
competition
resources
BIOTIC
EFFECTS
Community
Population
VITAL RATES
predation
DEMOGRAPHY
ABUNDANCE
DISTRIBUTION

feeding
breathnig
temperature
water



Thank you for your attention

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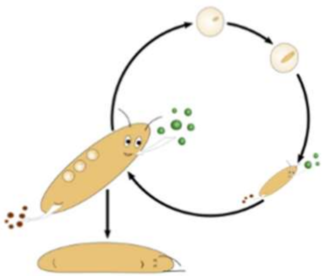

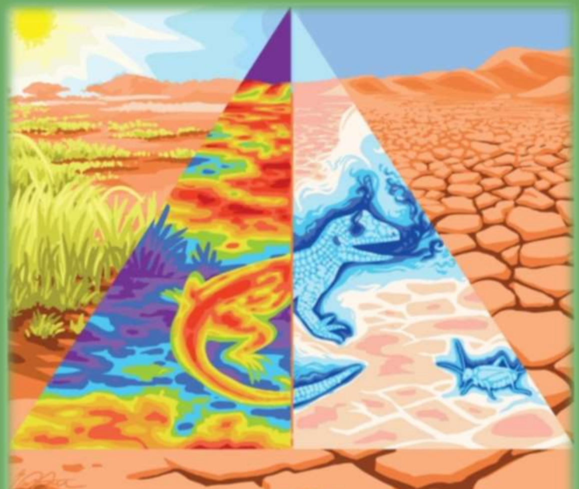
Credit: Elia Pirtle

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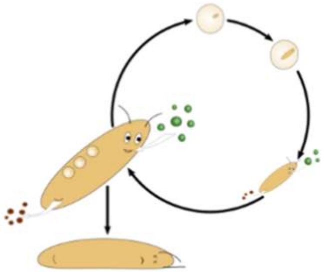
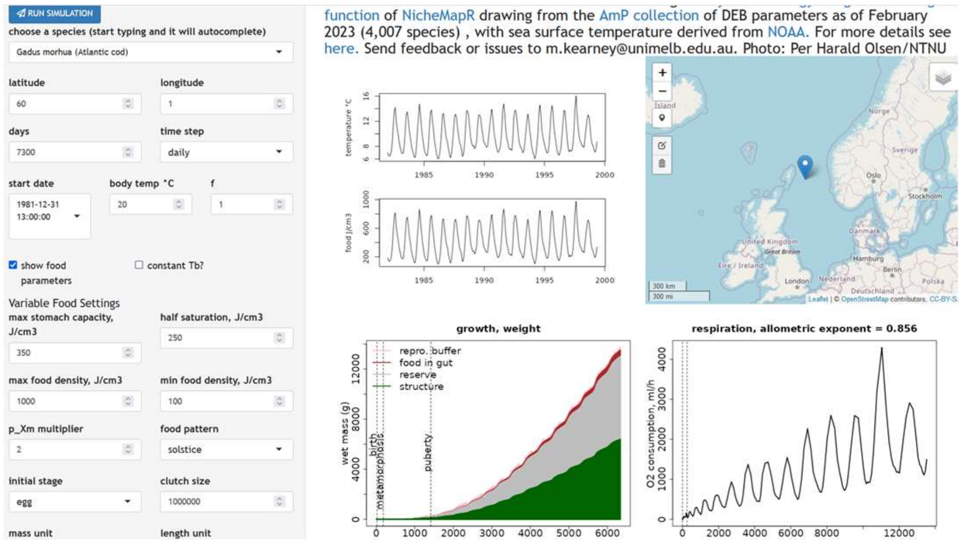
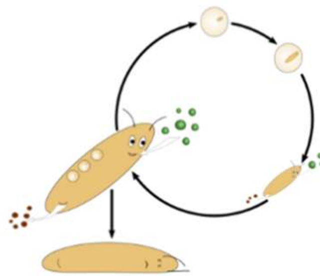


Simulating trajectories with DEB theory: NicheMapR Shiny Apps





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NicheMapR

Modelling the thermodynamic constraints on life

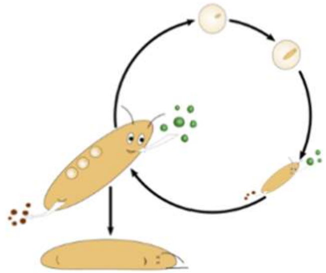
Twitter

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?*



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

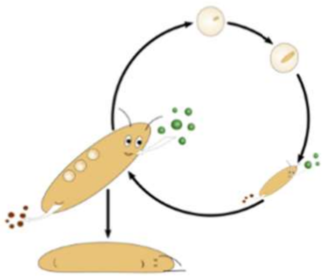
Dynamic Energy Budget Models

Ectotherm Models

Endotherm Models

Microclimate Models

Plant Models



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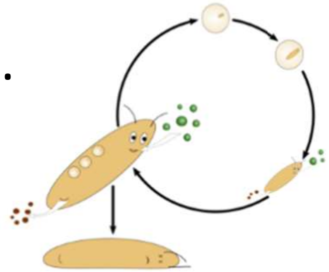
NicheMapR

Modelling the thermodynamic constraints on life

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

Dynamic Energy Budget 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



RUN SIMULATION

choose a species (start typing and it will autocomplete)

Daphnia magna (Waterflea)

days: 50

time step: hourly

temperature, °C: 20

f: 1

initial stage: egg

clutch size: 5

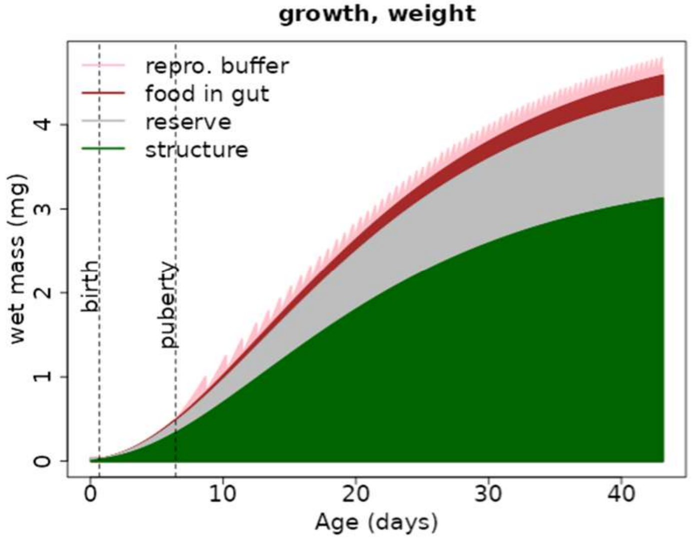
mass unit: mg

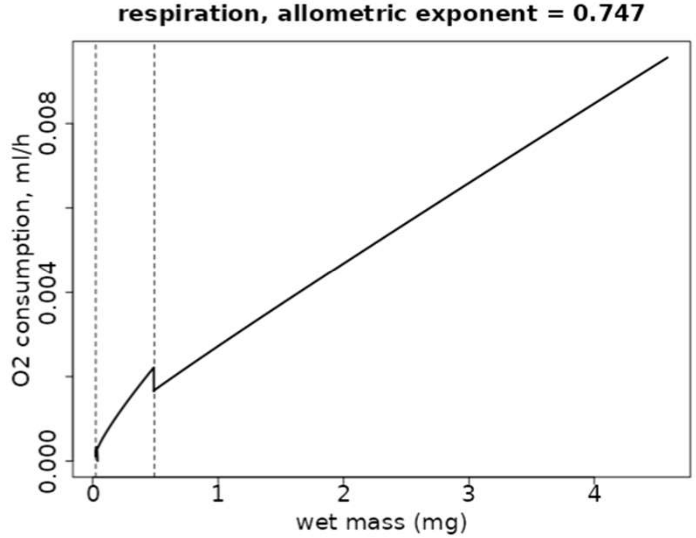
length unit: mm

z (size) multiplier - applies DEB covariation rules

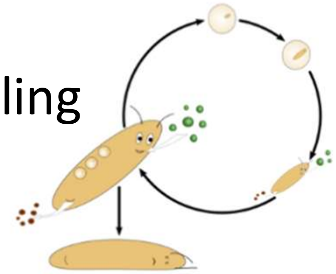
0 1 10

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/