From thermo-hydroregulation ecophysiology to climate niche modelling

Jean-François Le Galliard

Invited seminar, 2023

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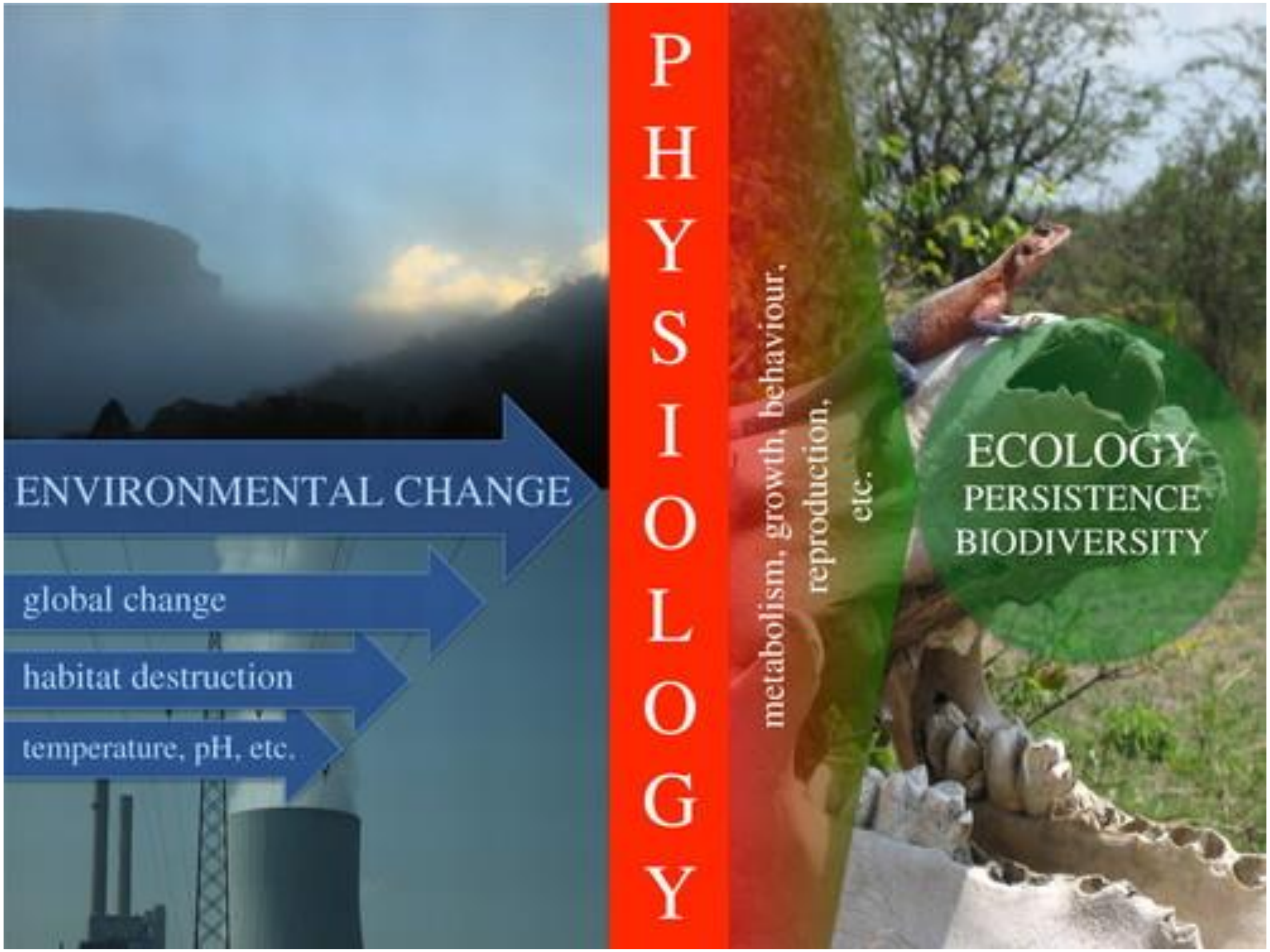
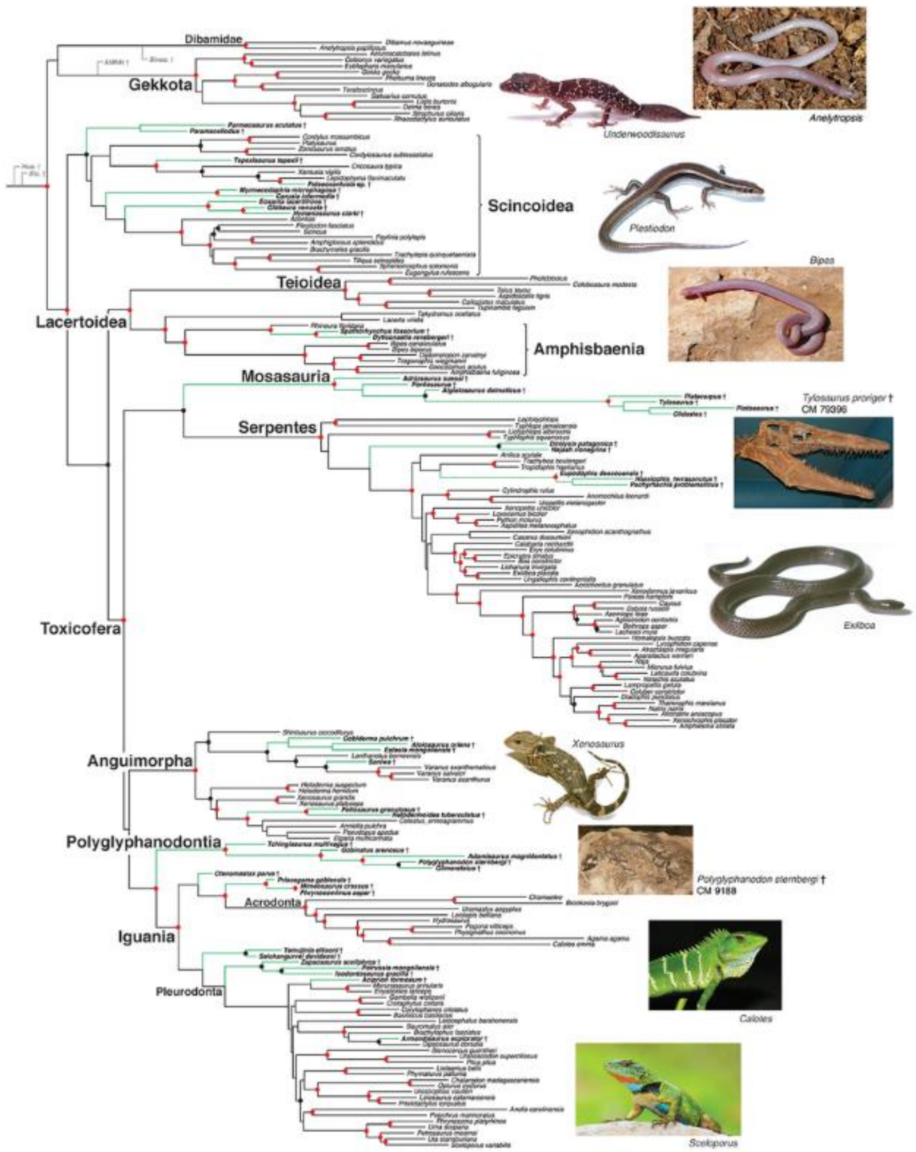
All silhouettes extracted from phylopic website

From physiology and behaviour to ecological patterns



Seebacher and Franklin. 2012. Determining environmental causes of biological effects: the need for a mechanistic physiological dimension in conservation biology. Philosophical Transactions of the Royal Society B: Biological Sciences

Focusing on squamate reptiles as model systems



Reeder, Townsend, Mulcahy and Noonan. Plos One. 2015

- About 12,000 identified species including all lizards, snakes, and amphisbenians
- Land Amniota vertebrates (with secondary colonization of oceans) belonging to the Tetrapoda super-class, the “reptiles” group (with sister taxon being crocodiles, dinosaurs and birds)
- Scaly skin with regular molting, highly mobile cranial bone morphology, ectothermic energetic style, continuous growth, extremely diverse morphologies and ecologies

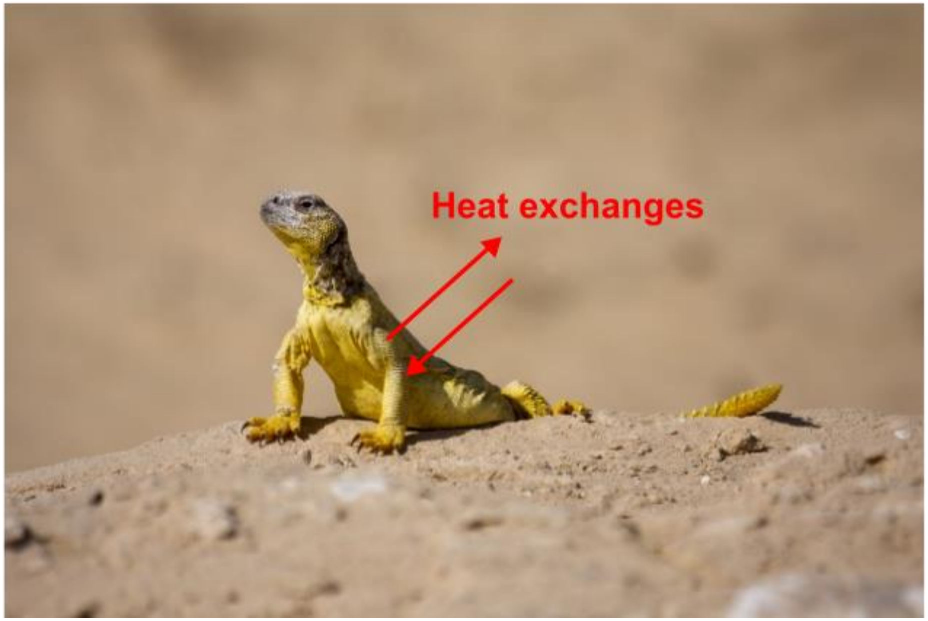
A group highly diversified in tropical areas and deserts

Overview of this talk

- **General concepts of thermal biology applied to terrestrial ectotherms**
- Hydroregulation: a missing component of the organismal vulnerability to climate warming
- Modelling the link between microclimate, behavioural thermoregulation and thermo-hydroregulation strategies

Thermal ecophysiology in metazoans (animals)

Ectothermic species

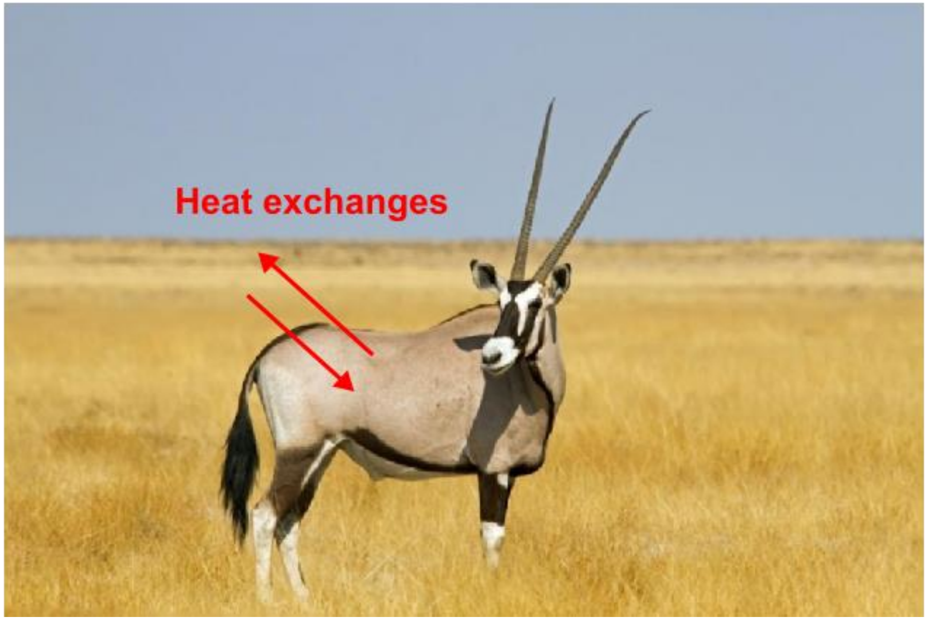


"Broad range" of body temperatures varying around a thermal preference

Behavioural regulation relying on environmental conditions

Some evaporative cooling and some metabolic heat production

Endothermic species



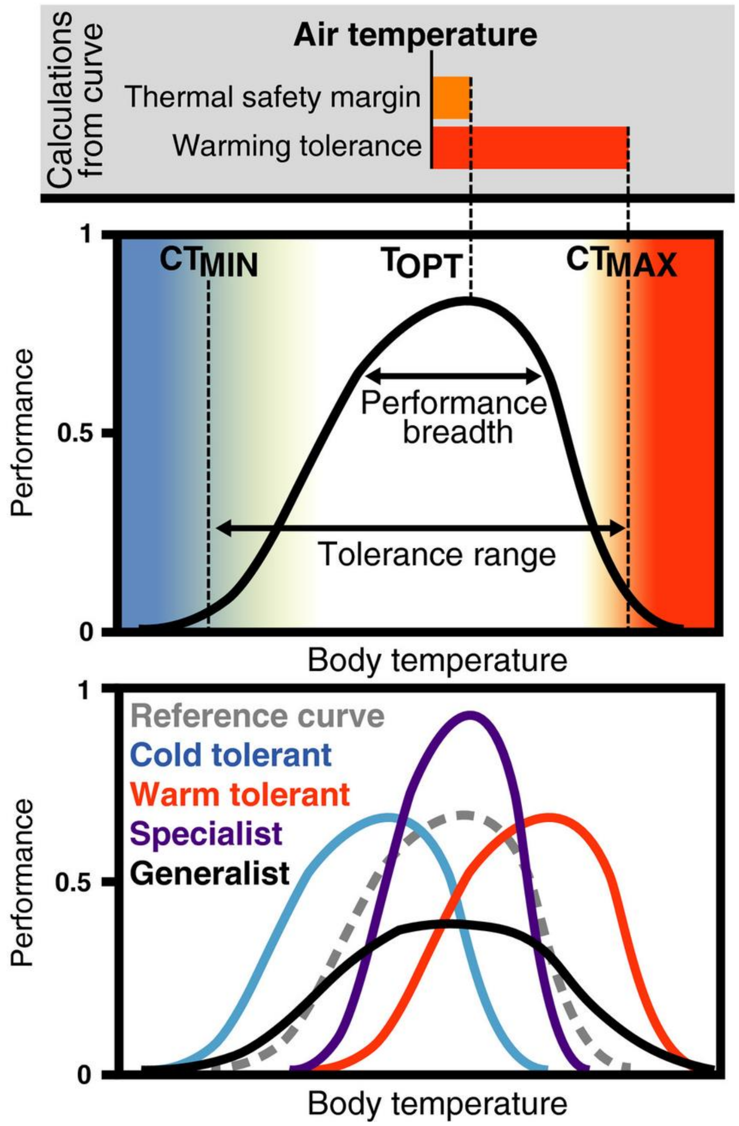
"Tightly regulated" body temperatures within a safety zone

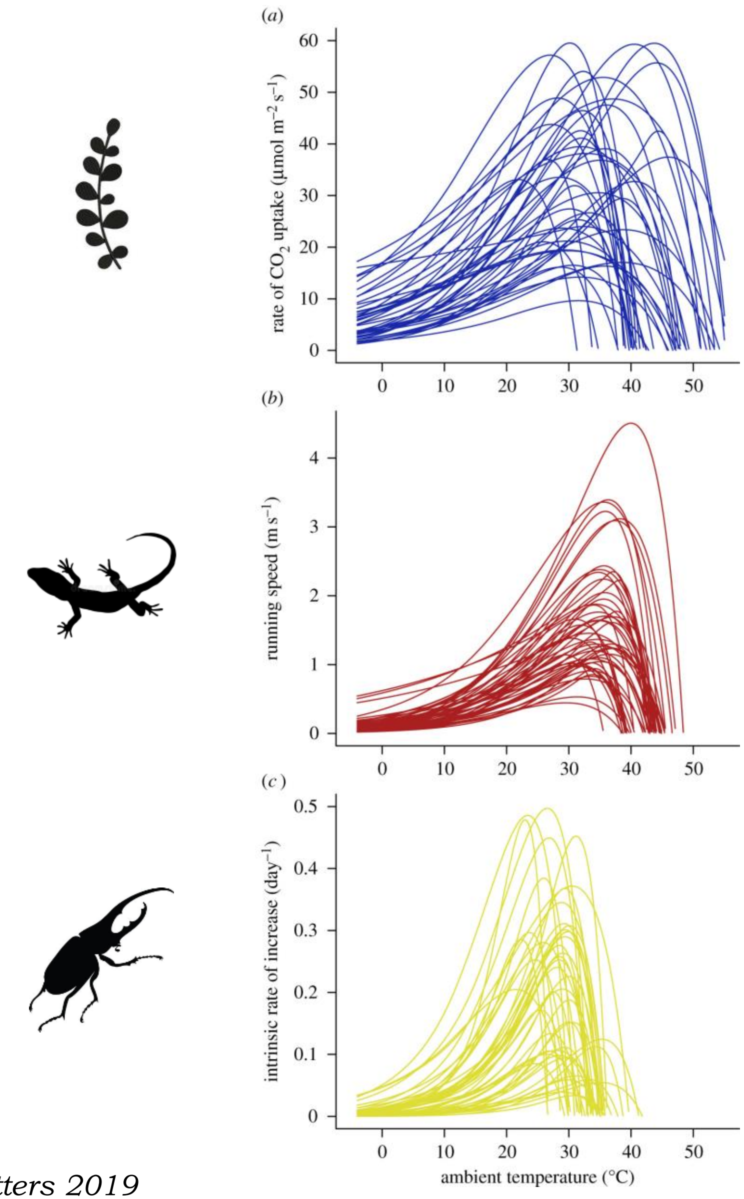
Metabolic heat production

Evaporative cooling

Some behavioural regulation

Thermal performance curves in ectotherms



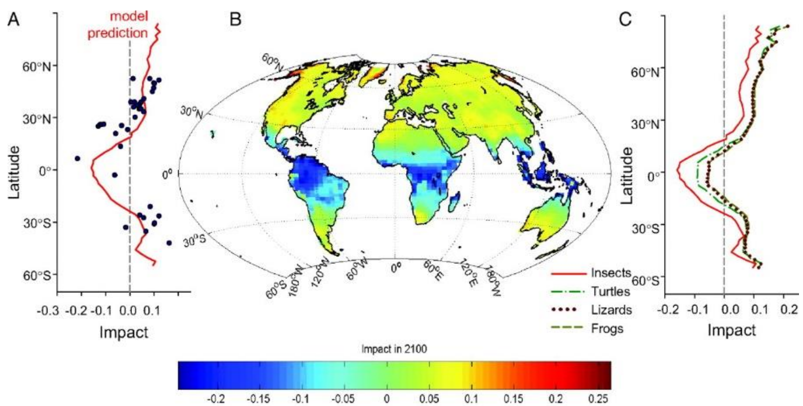


After Tuff et al. Ecology Letters 2013, Rezende & Bozinovic Biol. Letters 2019

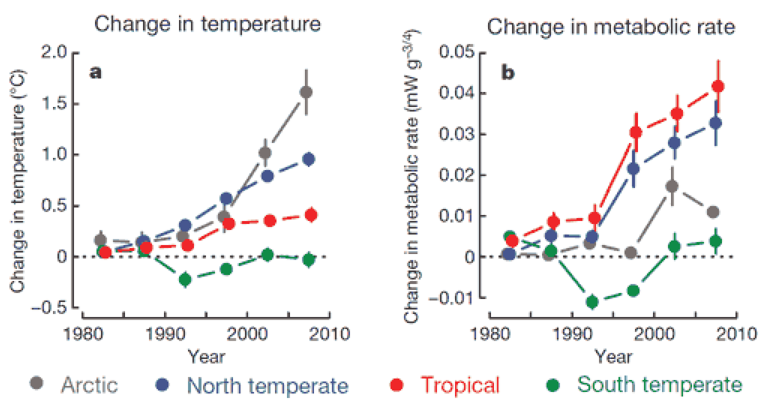
Thermal biology and the climate vulnerability of reptiles

Restricted activity time and increased overheating risks

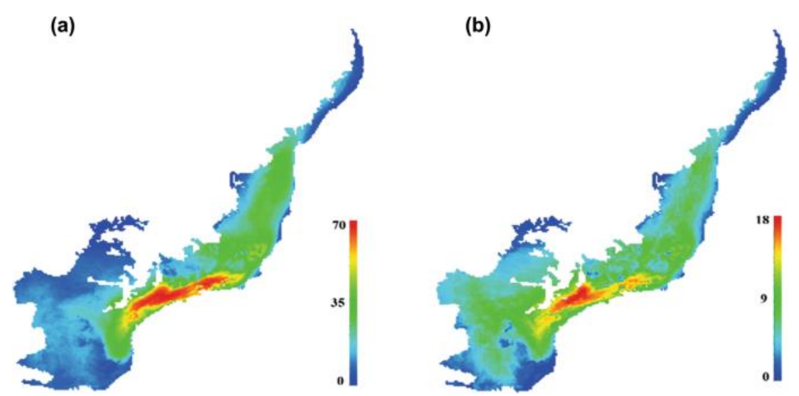
Reduced performances especially in thermal specialists



Energy imbalance due to thermal dependence of metabolism



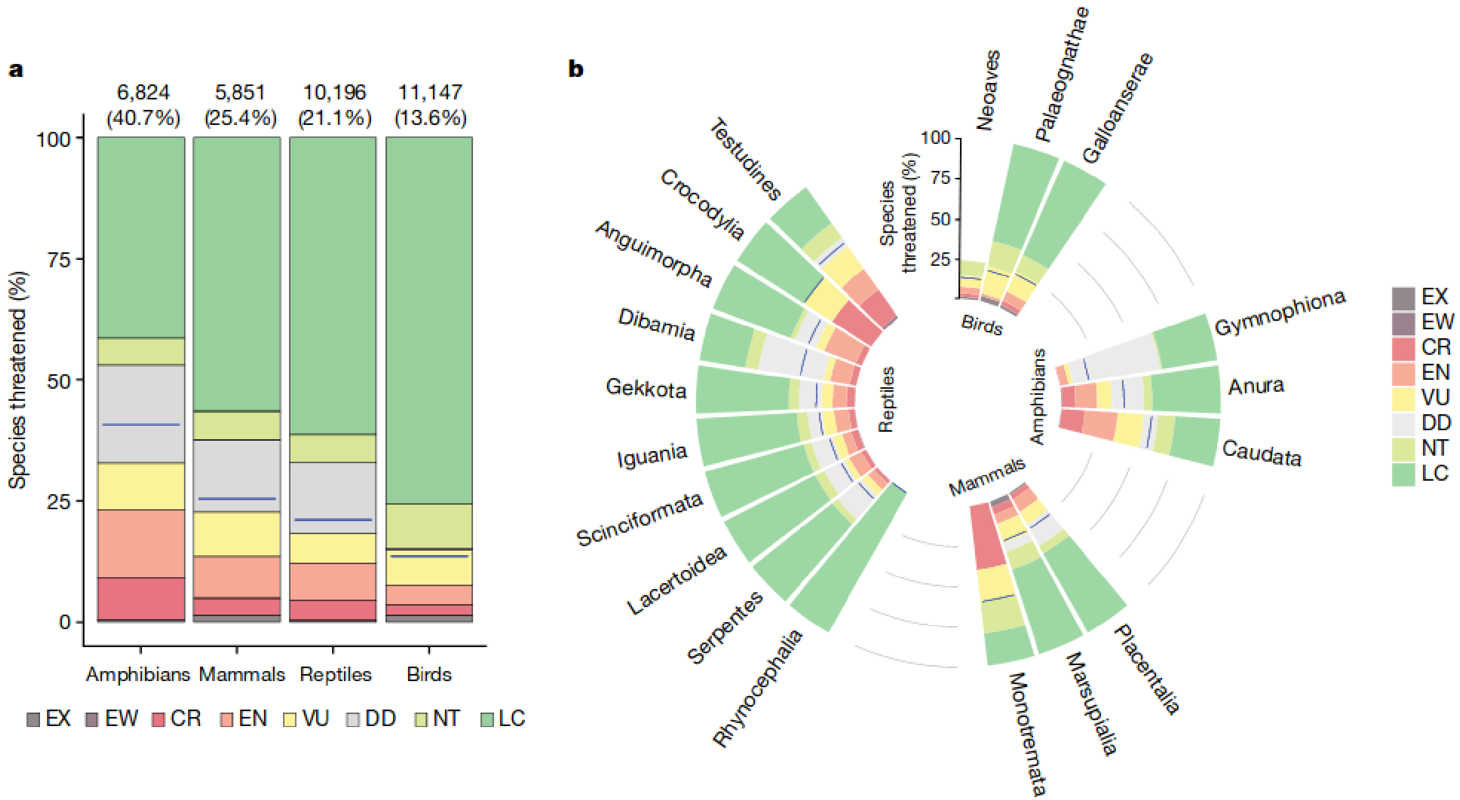
Shifting climate niche and dispersal requirements



Missing information about climate vulnerability

- Focuses on thermal biology traits instead of energy, nutrient and water budget
- Includes rough climate proxies of climate conditions instead of microclimates
- Generally lacks information about the link between functional traits and physiological processes on one hand and demographic traits and processes on the other hand
- Generally not backed up with detailed field data

Climate warming not the dominant cause of extinction



EX = extinct
EW= extinct in the wild
CR = critically endangered
EN = endangered
VU = vulnerable
DD = data deficient
NT = near threatened
LC = least concern

Habitat loss and land use change (>25-50%)

Invasive species, especially for insular species (15-20%)

Exploitation and illegal trafic (10-15%)

Climate warming is not the dominant threat (<5%) but poorly assessed

Cox et al. 2017. A global reptile assessment highlights shared conservation needs of tetrapods. Nature.

Overview of this talk

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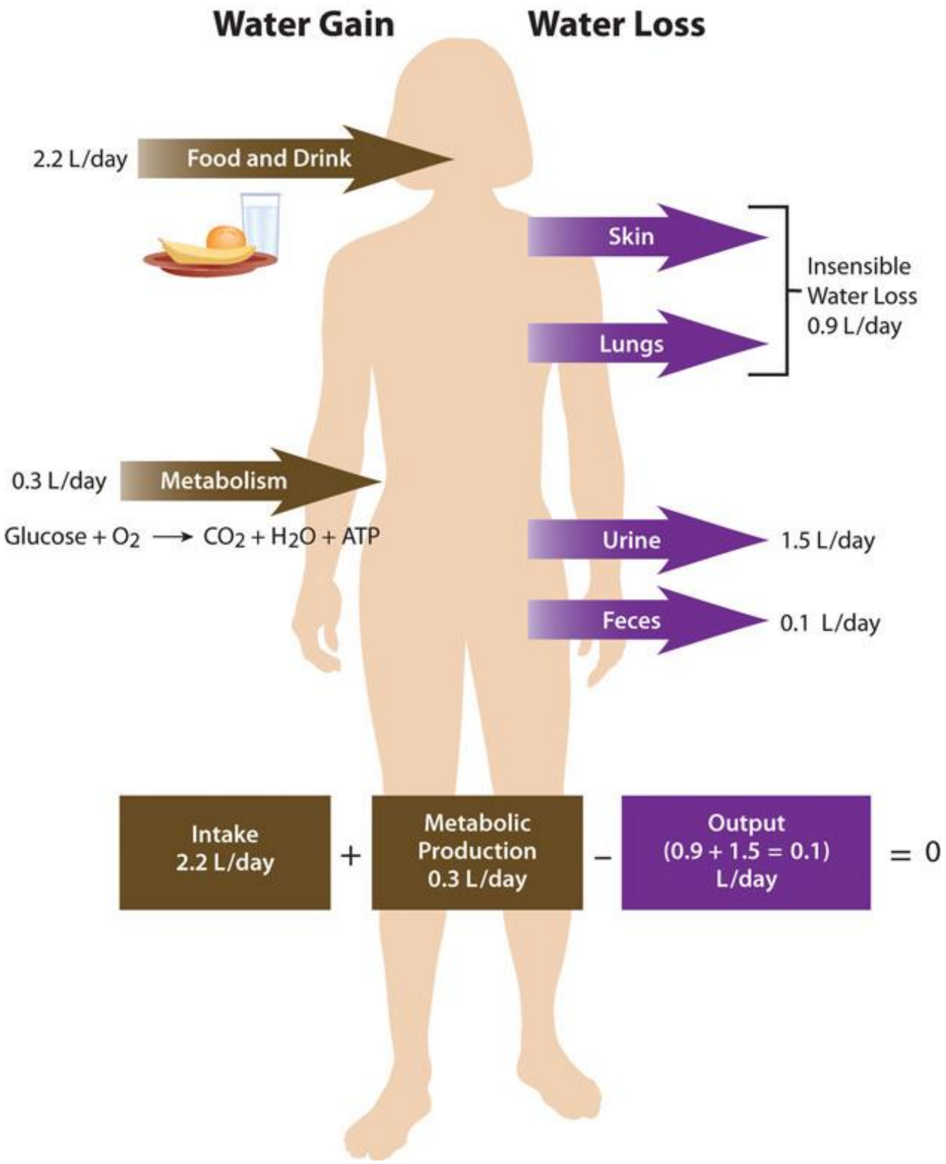
- Modelling the link between microclimate, behavioural thermoregulation and thermo-hydroregulation strategies

Water balance regulation in animals



Regulation of the water balance (hydroregulation) in animals involves

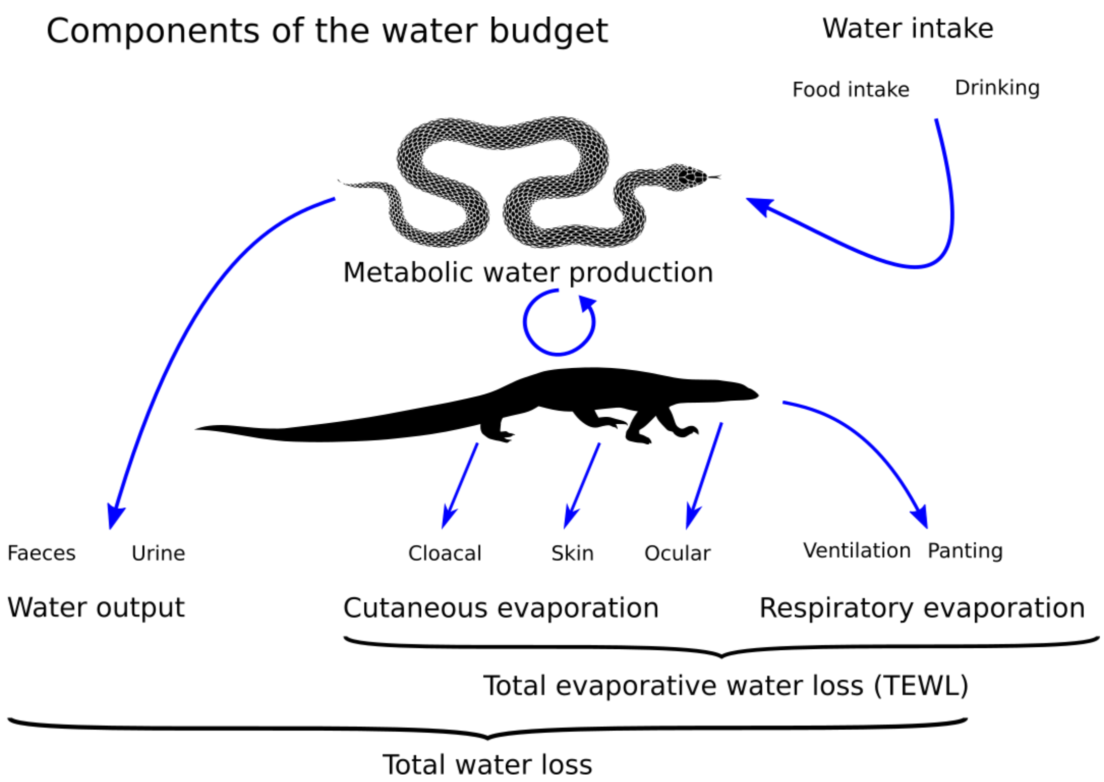
Inputs from food and free standing water = *foraging behaviour and habitat selection*

Metabolic water production= *basal and activity metabolism, especially lipid metabolism*

Water loss through the skin, lungs and urine or faeces = *evaporative water loss, respiration and ventilation, osmoregulation*

From Regulation of Water Balance", section 7.3 from the book An Introduction to Nutrition (v. 1.0)

Water balance regulation in squamate reptiles



After Le Galliard et al. 2021

Open questions

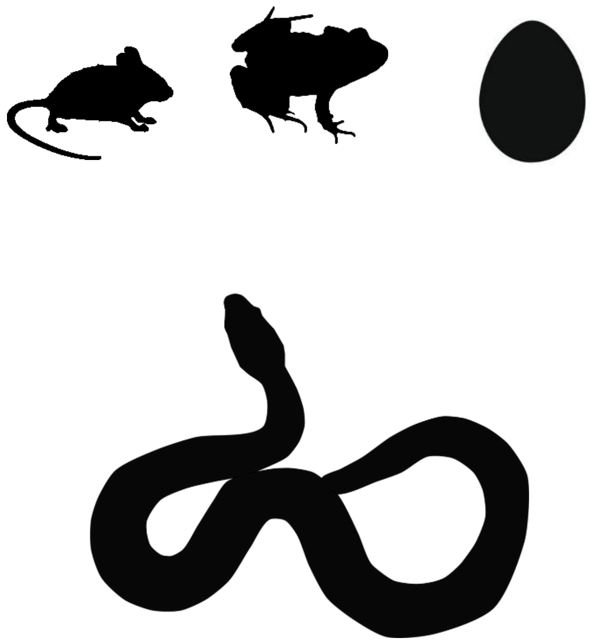
Relevance of dietary water intake

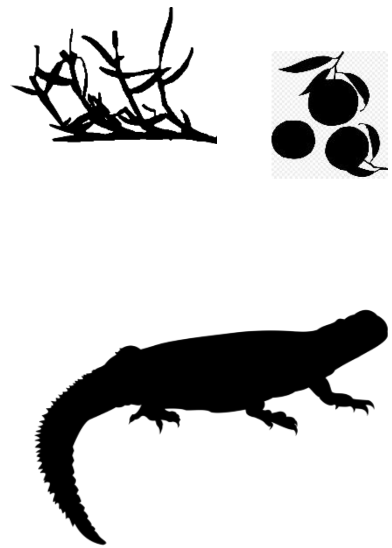
Acclimation and adaptation of TEWL

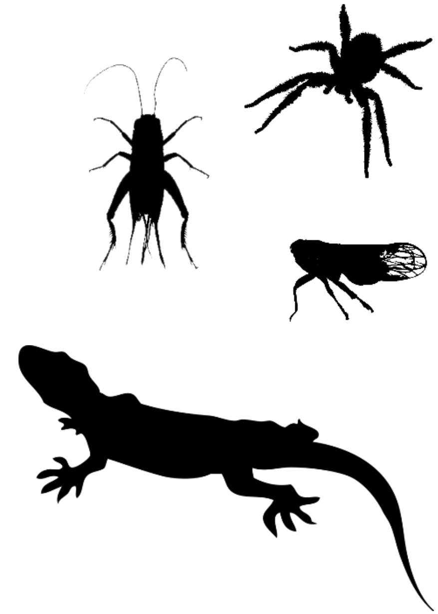
Contribution of cutaneous versus respiratory mechanisms

Behavioural control of TEWL

Dietary water intake in reptiles







CARNIVOROUS

High protein content and low water content preys, intermittent feeding

Negative net water intake

HERBIVOROUS

Low protein content, high water content, constant feeding

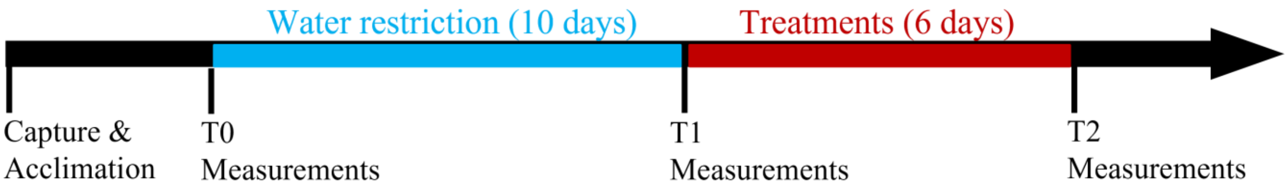
Positive net water intake

INSECTIVOROUS

Variable prey types, constant feeding

Unknown net dietary water intake

Dietary water intake in an insectivorous lizard



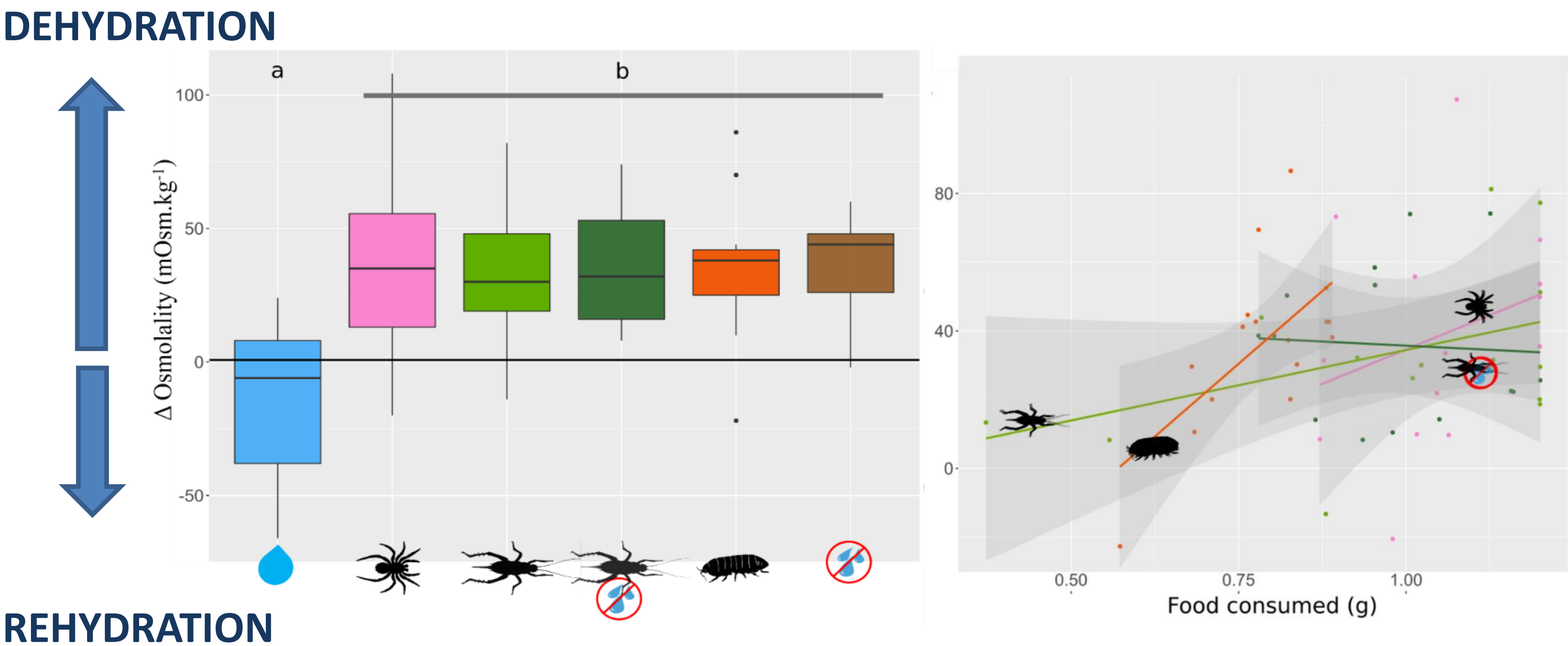
Treatments:

- **Hydrated control (water only)**
- **Food only**
  - Spiders
  - Hydrated Crickets
  - Dehydrated Crickets
  - Woodlice
- **Dehydrated control (no water no food)**

Hypothesis 1. Food supplementation allows lizards to maintain their water balance at a level somewhere between the dehydrated control group and the hydrated control group with drinking water

Hypothesis 2. High quality food (spiders and hydrated crickets) is a better diet with regard to water balance regulation

Dietary water intake in an insectivorous lizard

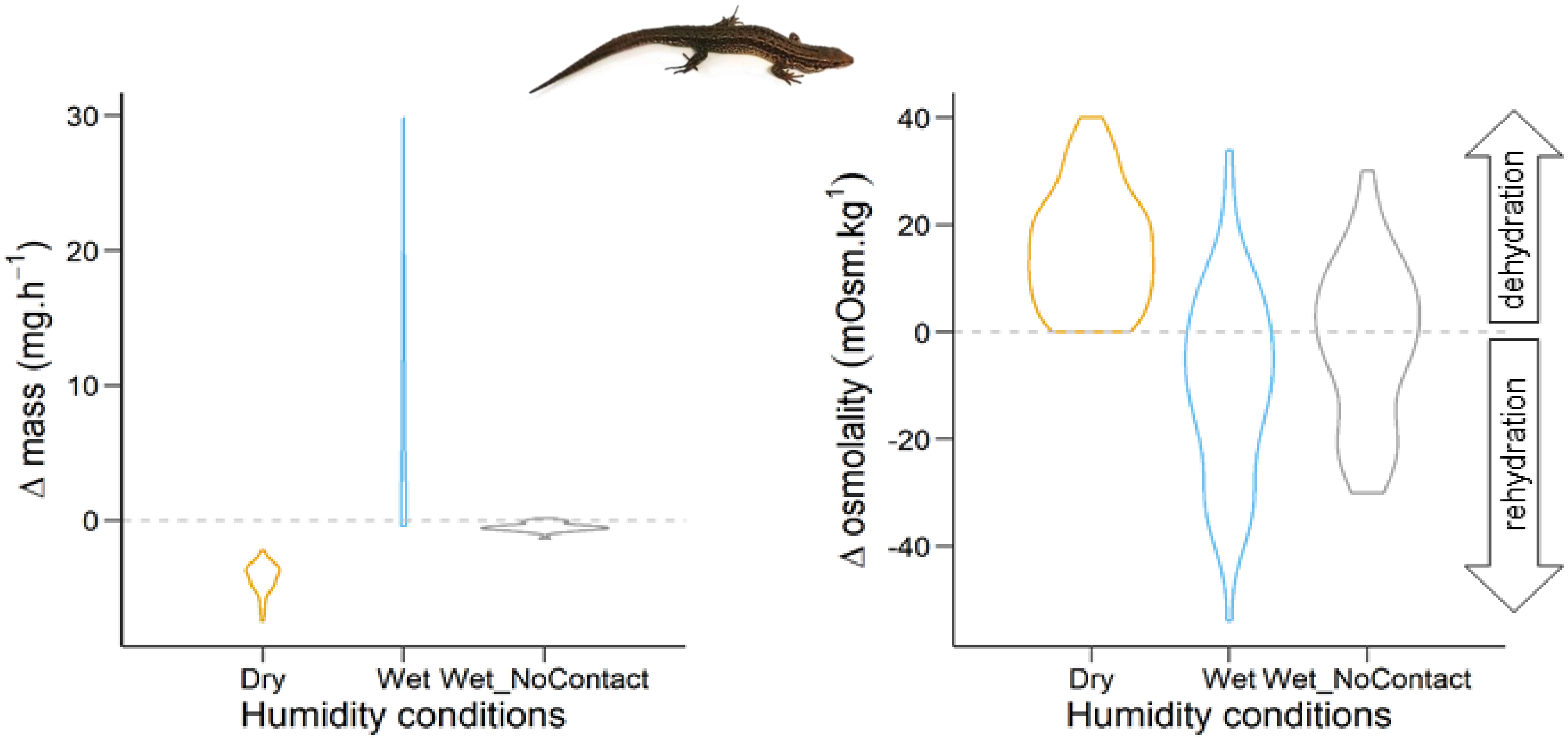


Food supplementation does not allow to restore water balance irrespective of food type

Food consumption is **positively** correlated to dehydration, possibly because foraging and digestion effort slightly increase water loss

After Chabaud et al. unpub data

Unexpected rehydration mechanism: skin water intake

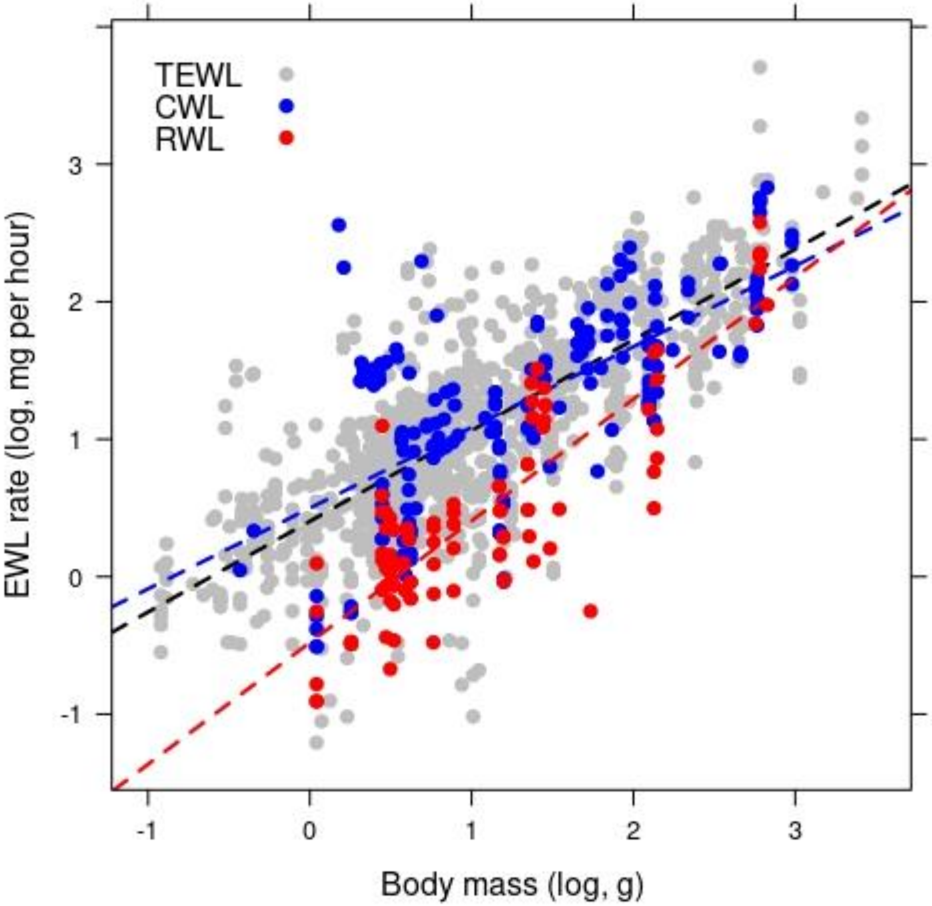


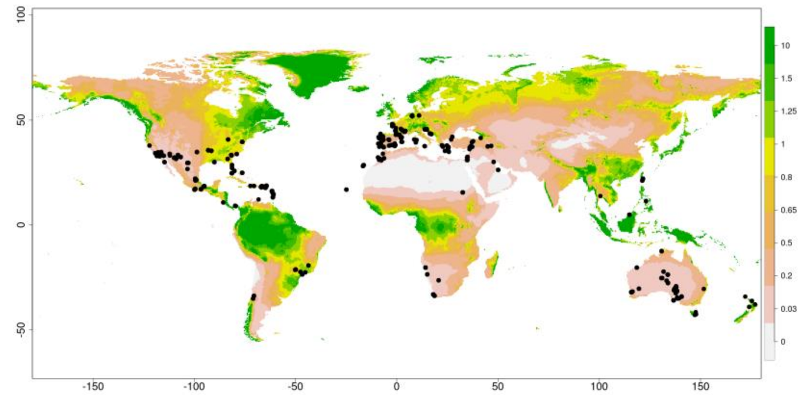
Nighttime conditions

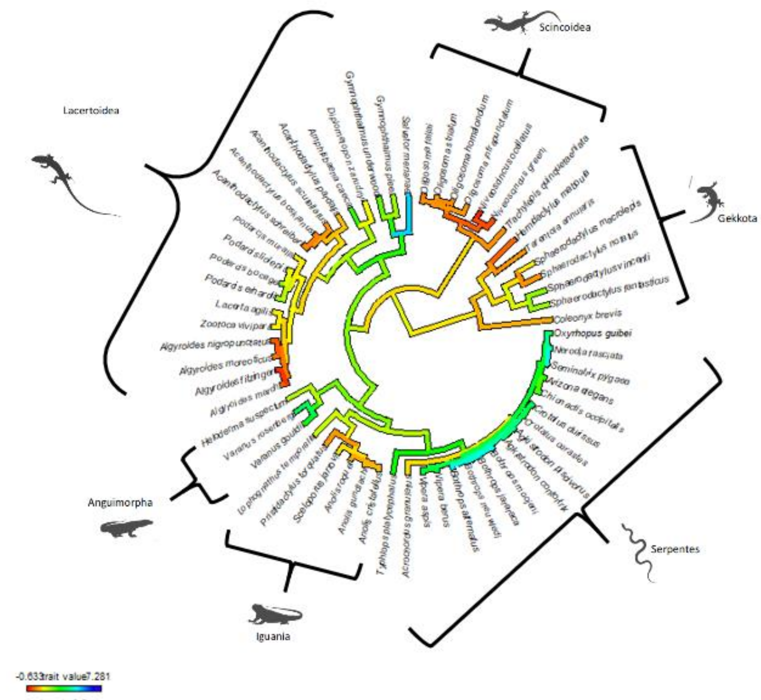
1. Dry = dry substrate
2. Wet = wet substrate in contact with lizard
3. Wet, not contact = wet substrate without contact

After Dupoué et al. unpub data

Standard evaporative water loss (EWL) rates across species

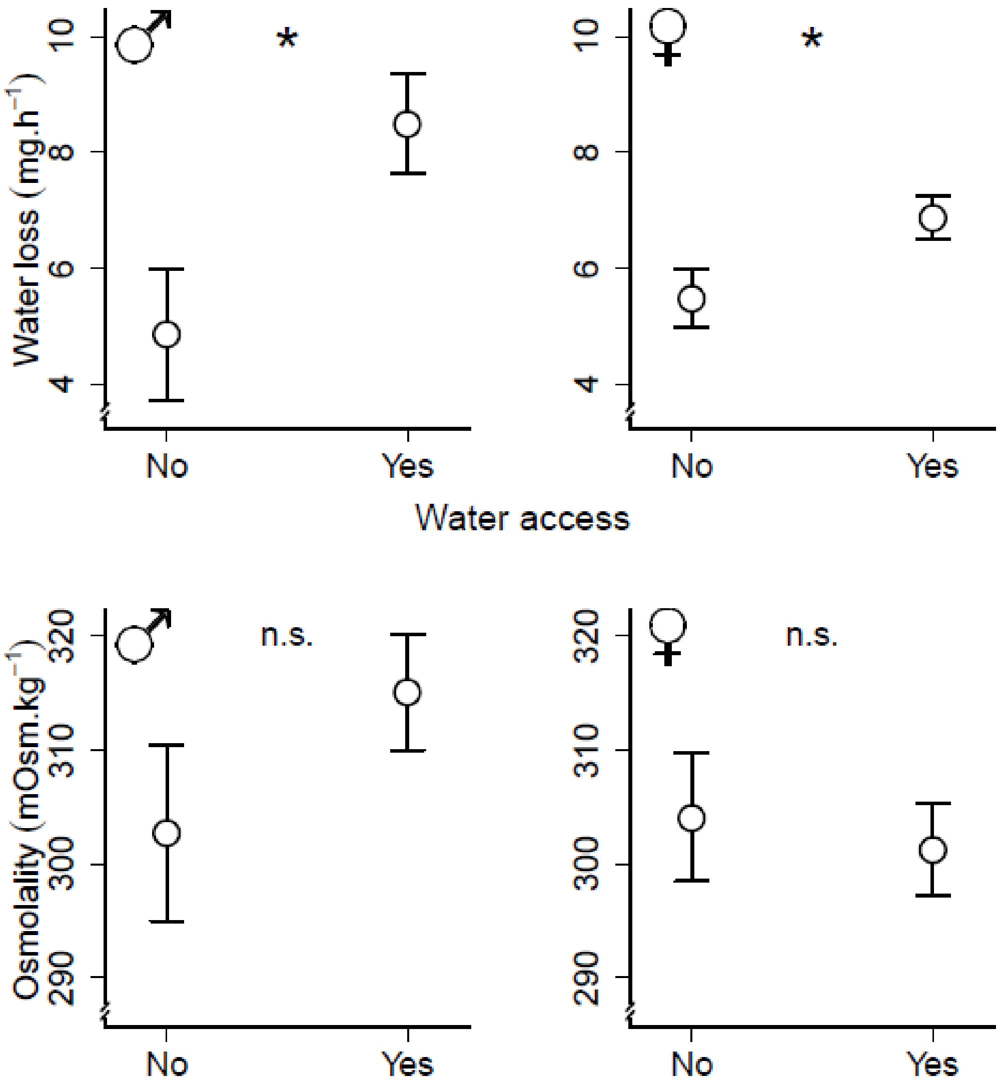






After Le Galliard et al. 2021, Chabaud unpub. data

Acclimation and adaptation of EWL

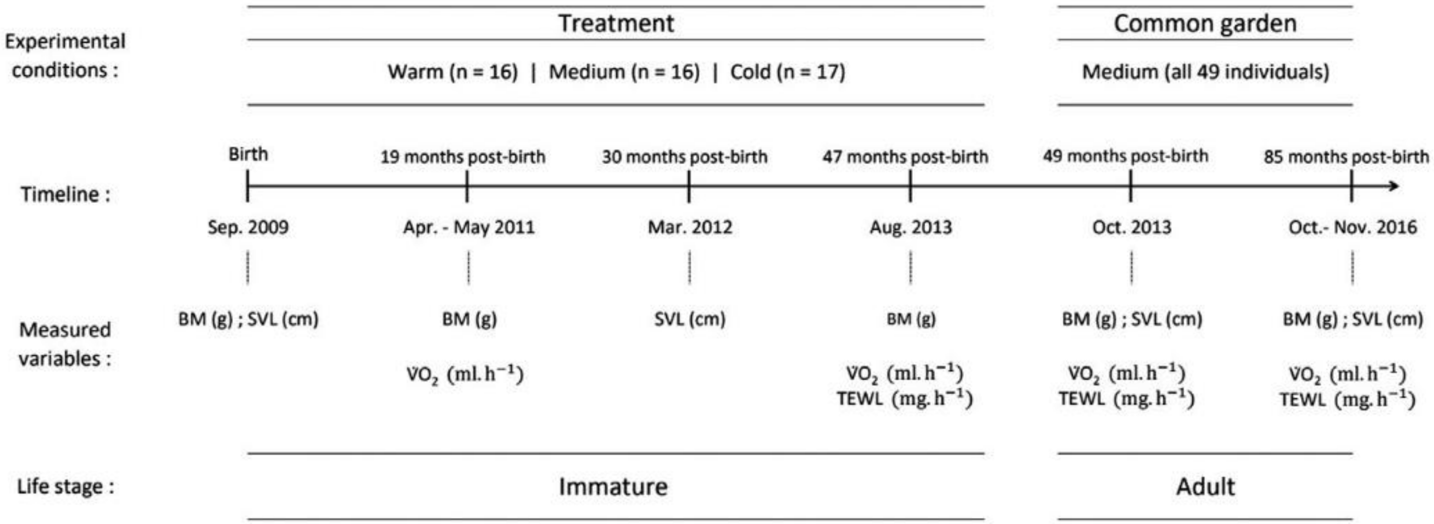


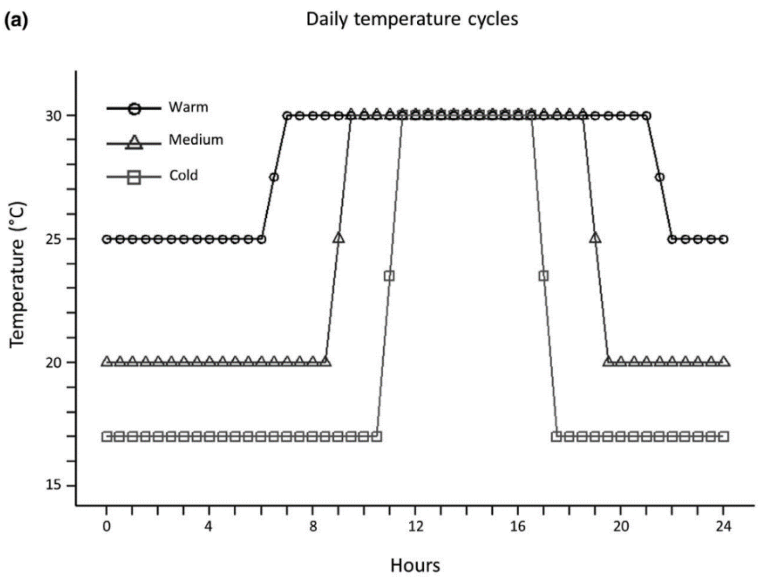
Water loss: lower standard water loss rates in habitats without access to free standing water

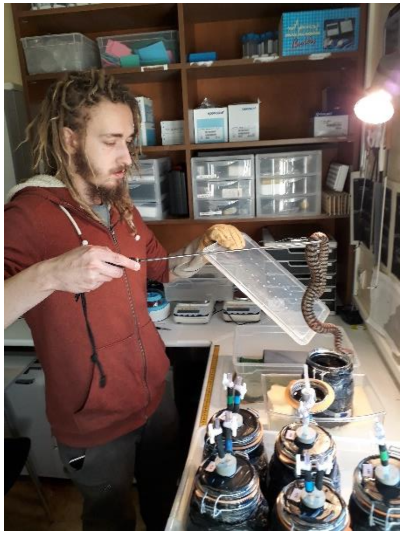
Water balance: plasma osmolality similar in habitats with or without access to free standing water (homeostatic state)

Dupoué, A., Rutschmann, A., **Le Galliard, J.-F.,** Miles, D. B., Clobert, J., DeNardo, D., Brusch, G. A. and S. Meylan. 2017. Water availability and environmental temperature correlate with geographic variation in water balance in common lizards. **Oecologia** 185(4):561-571

Phenotypic plasticity of TEWL



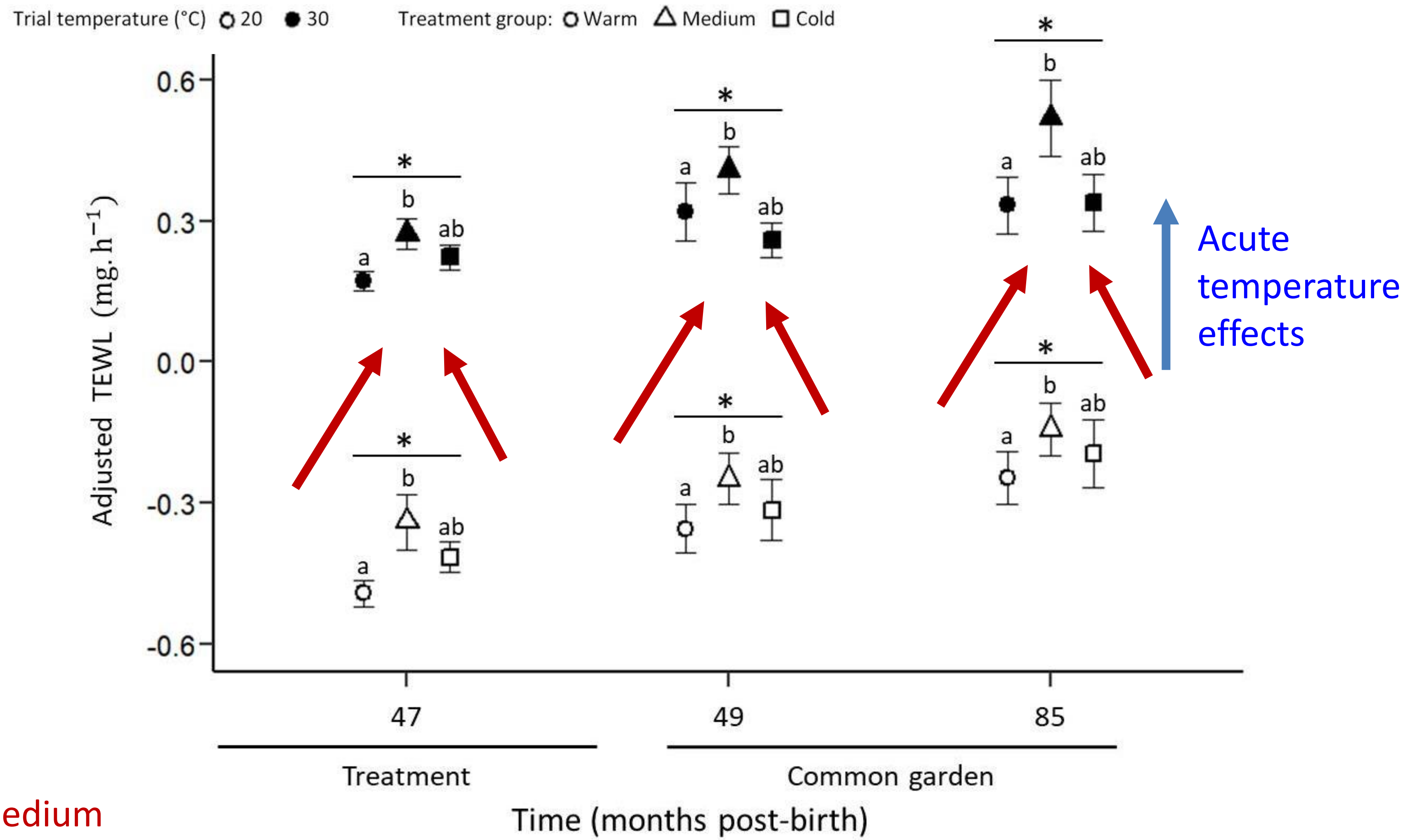




Study performed at CEBC by Olivier Lourdais with PhD student Mathias Dezetter

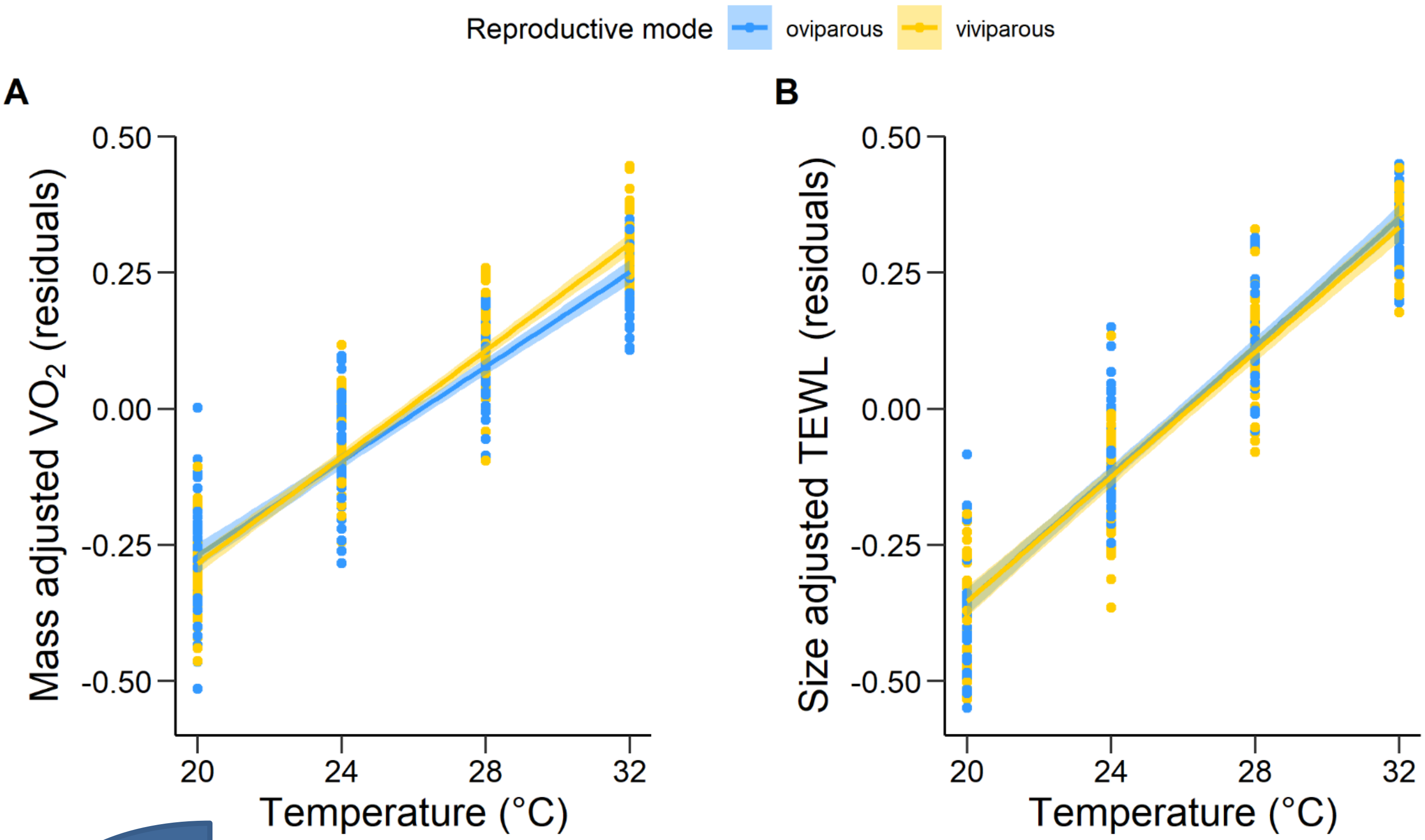
Dezetter et al. Functional Ecology 2021

Persistent phenotypic plasticity of TEWL



Medium temperature persistent acclimation

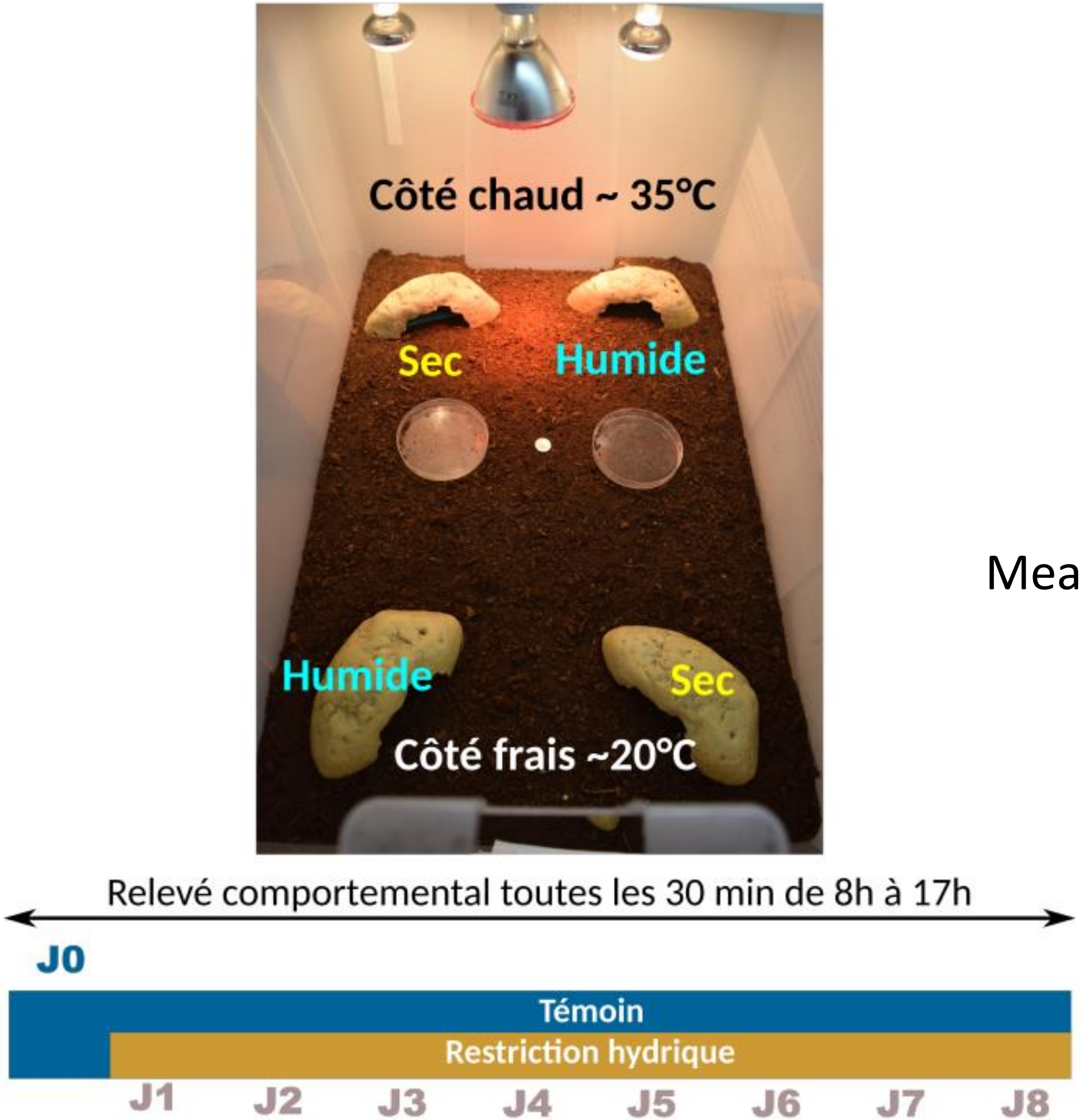
Thermal dependence of EWL



High temperatures and low ambient humidity should be avoided to reduce TEWL

After Dupoué, Lourdais and Le Galliard, unpub data

Behavioural reactions to dehydration risks



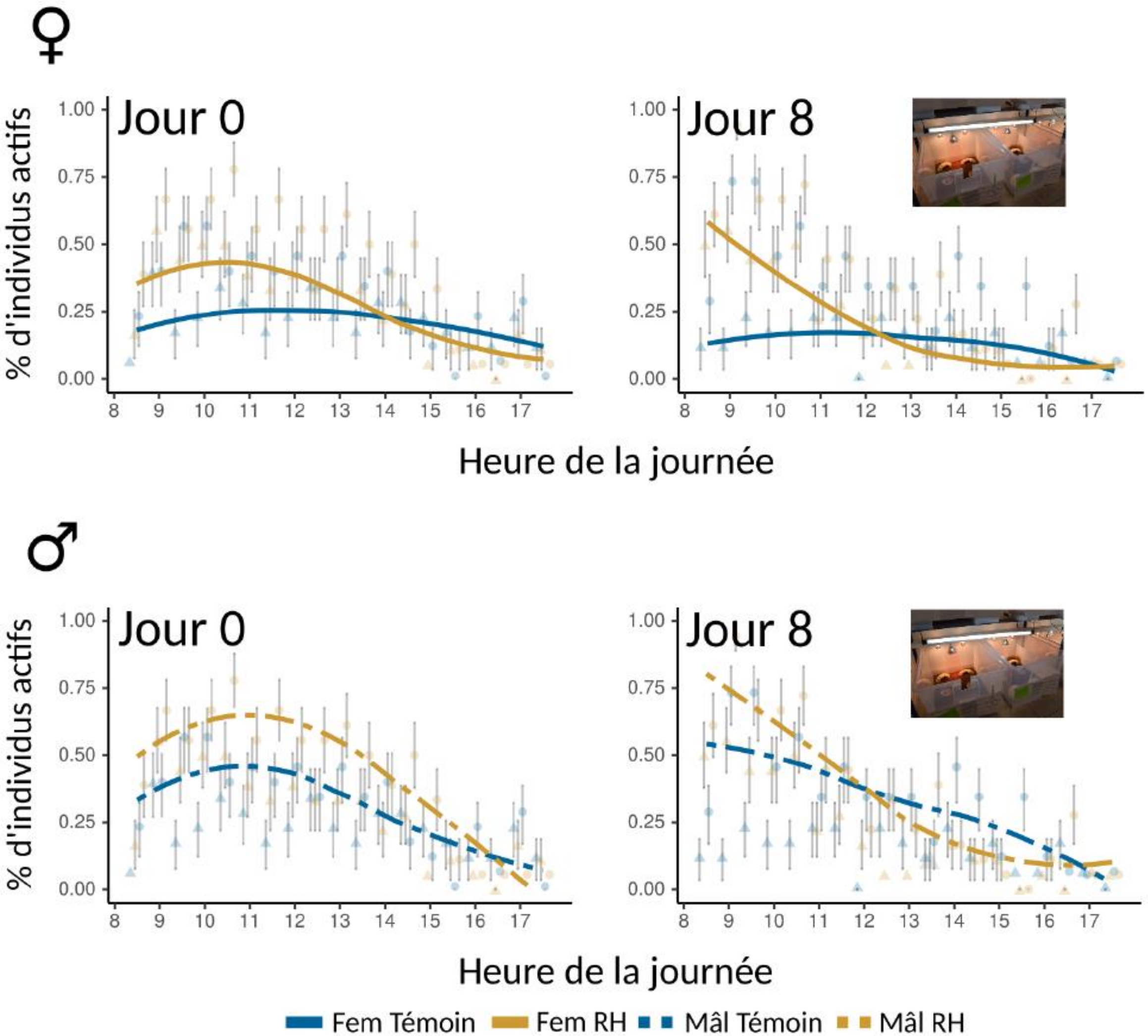
Quantification of activity and thermoregulation effort

Analysis of shelter use

Measurement of body temperatures

After Rozen-Rechels et al. Oikos 2020

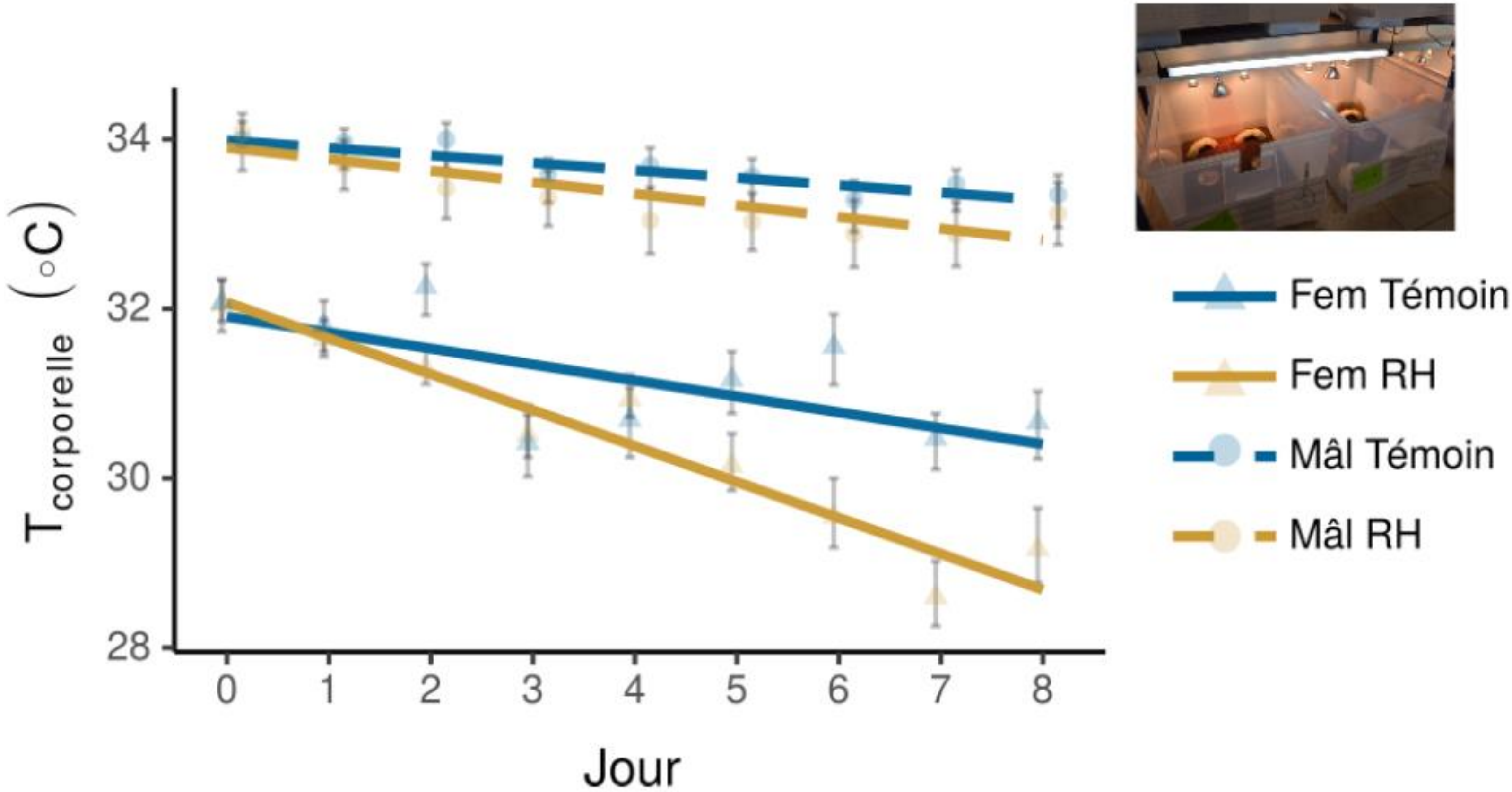
Behavioural reactions to dehydration risks



GLMM : sexe*RH*jour $\chi^2_1 = 18.23, p =< 0.0001$

After Rozen-Rechels et al. Oikos 2020

Behavioural reactions to dehydration risks



Dépression thermique plus forte chez les femelles restreintes en eau.

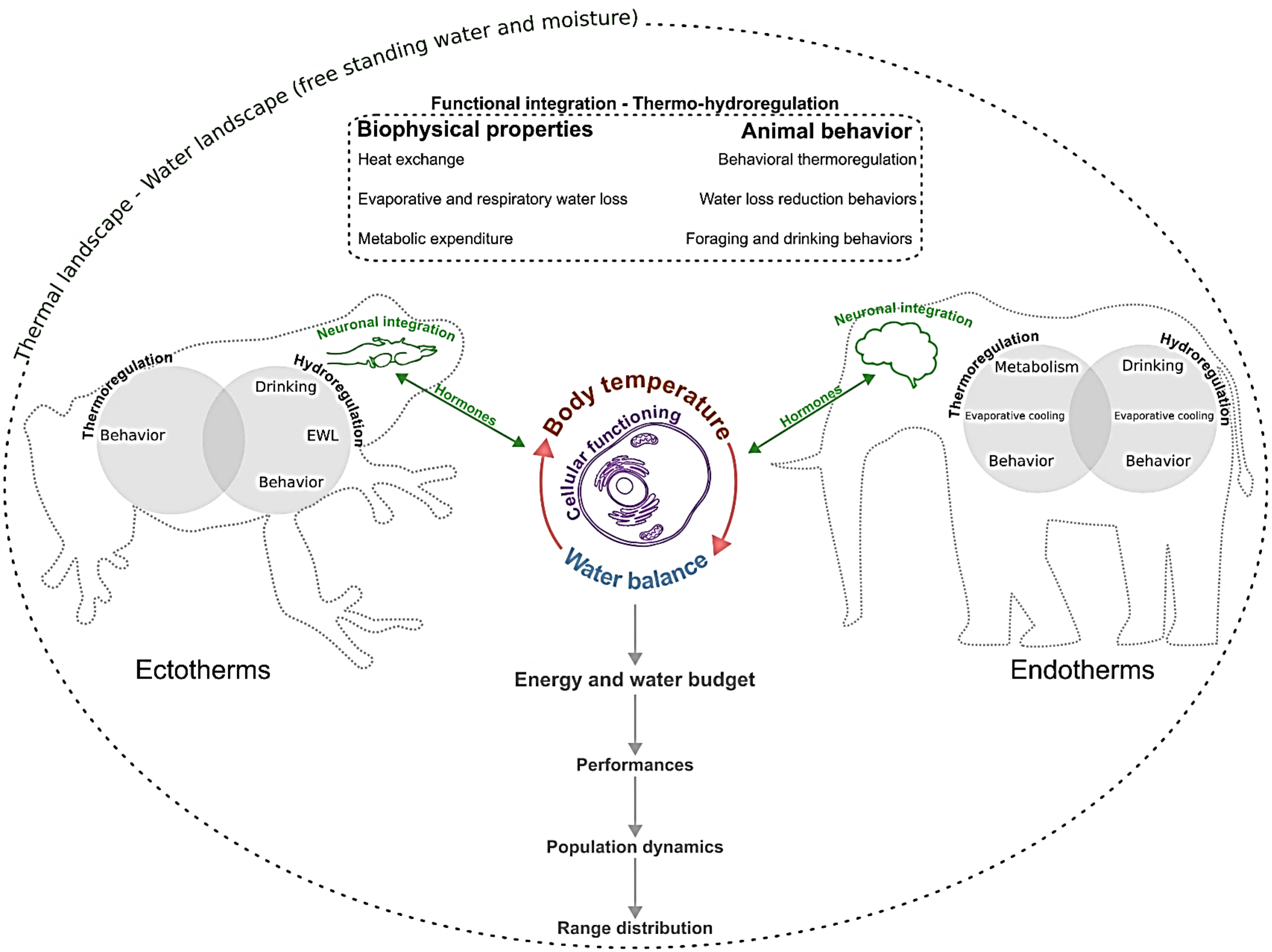
LMM : sexe*RH*jour $F_{1,3258} = 4.61$, $p = 0.03$

After Rozen-Rechels et al. Oikos 2020

Short conclusions

- TEWL, especially through the skin, represents a significant avenue of water loss in reptiles
- Many reptile species might be highly dependent upon drinking water and moisture to restore their water balance
- Water balance regulation involves flexible behavioural mechanisms as well as adaptive acclimation responses
- Water balance regulation can conflict with thermoregulation needs especially at high temperatures and during drought events, leading to potential “sub-optimal” thermoregulation

The thermo-hydroregulation concept



After Rozen-Rechels et al. Ecology Evolution 2021

Overview of this talk

- General concepts of thermal biology applied to terrestrial ectotherms

- Hydroregulation: a missing component of the organismal vulnerability to climate warming

- **Modelling the link between microclimate, behavioural thermoregulation and thermo-hydroregulation strategies**

Overview of this talk

- General concepts of thermal biology applied to terrestrial ectotherms
- Hydroregulation: a missing component of the organismal vulnerability to climate warming
- Pace-of-life acceleration and physiological tipping-points in response to climate warming
- **Modelling the link between microclimate, behavioural thermoregulation and thermo-hydroregulation strategies**

From physiology to the life history and the climate niche

- The physiology-life history nexus posits that life history and population dynamics can be constrained by physiological mechanisms
- We have collected extensive data about the thermo-hydroregulation strategies including behavioural traits, physiological traits and data on static and labile properties of these traits
- How can we use this knowledge to predict current and future life history strategies and range distribution of these species ?

The answer is mechanistic modelling !

- A mechanistic model uses **individual-level processes** constrained by functional traits such as physiology and behaviour to infer **demographic-level processes**

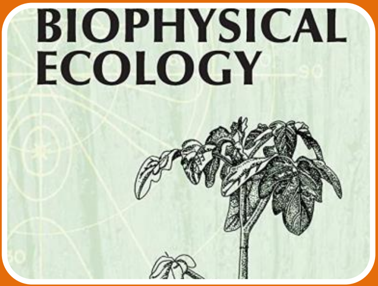
- This mechanistic model should be able to (1) describe the environmental conditions, especially climate conditions, (2) provide a quantitative description of the energy and water budget of the organism, and (3) integrate this budget into a prediction of the life history and population dynamics

- To do so, we can combine three kinds of models: microclimate physical models, biophysical models of the energy and water budget, and dynamic energy budget of the life history

NicheMapR as a platform to run the models

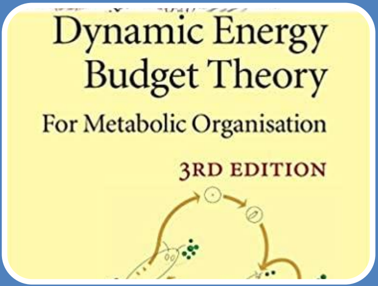
Microclimate model

- Predicts spatial and hourly variability in climate conditions
- Requires input about real weather conditions or gridded climatic and environmental data at any spatial scale
- Can predict ground microclimates in vegetation and soil for example



Biophysical thermo-dynamic model

- Coupled energy, mass and water budget model
- Constrained by biophysical properties of organisms and behavioural routines
- Uses inputs from the microclimate model to predict instantaneous energy and mass balance

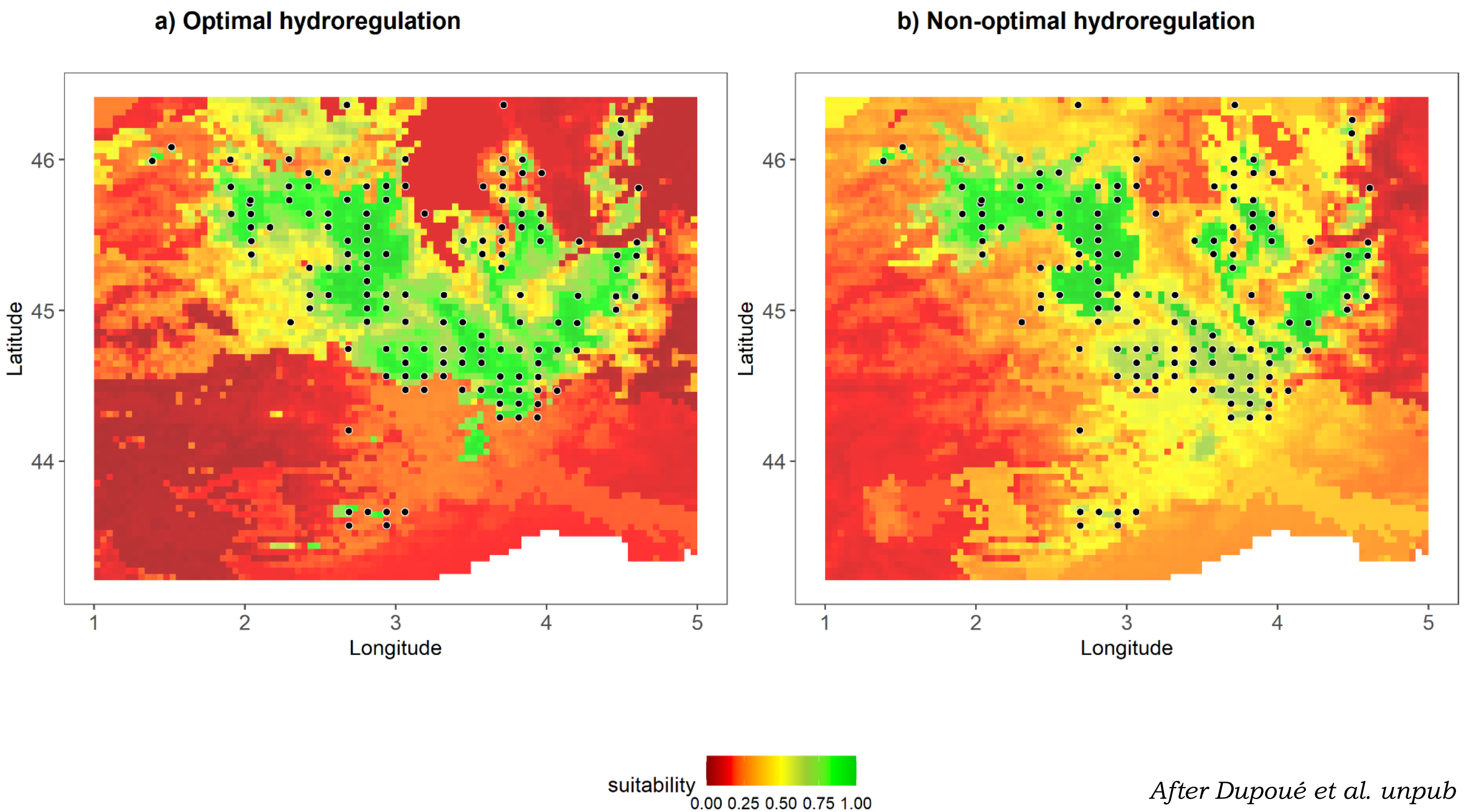


Dynamic energy budget model

- An ontogenic model of acquisition and allocation of water and energy in growth, reproduction and survival using inputs from the thermodynamic model
- Describes reserve, structure and maturation/reproduction through life using knowledge from metabolic theory

Application to occurrence data in Massif Central

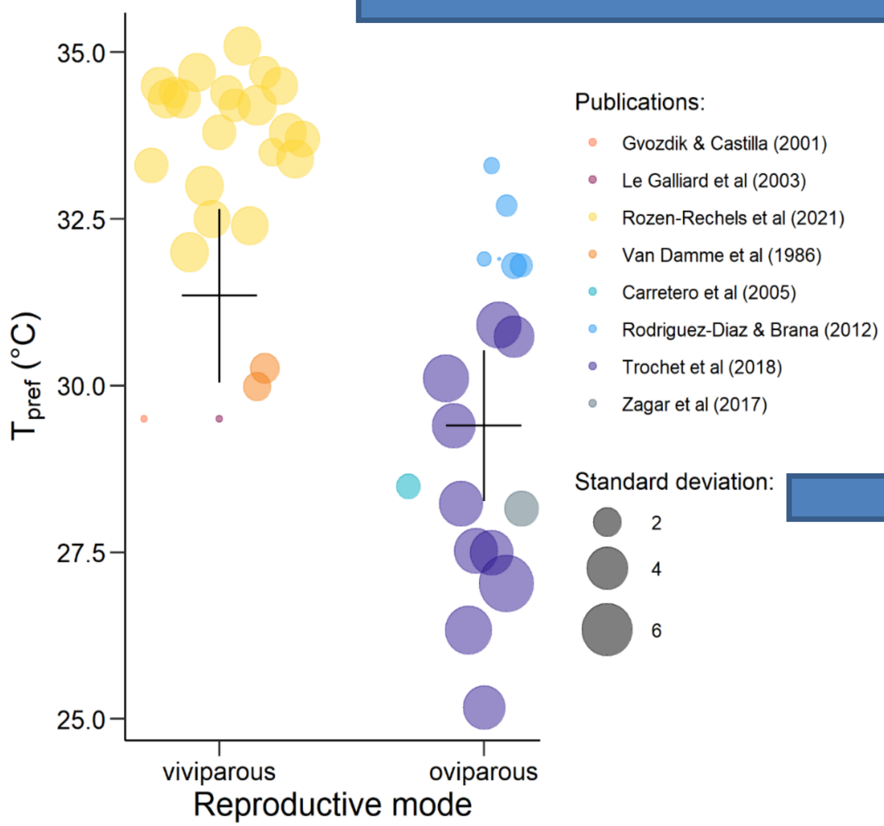
Microclimate predictions calculated with WorldClim database, thermodynamic model parameterized for a juvenile lizard under scenarios of water balance with or without nighttime skin drinking, dynamic energy budget modelling of growth and maintenance during the first year of life, habitat suitability calculated with GBIF occurrence database



After Dupoué et al. unpub data

Application to analysis of viviparity versus oviparity

Microclimate predictions calculated with WorldClim database, thermodynamic model parameterized for an adult female lizard with oviparous or viviparous reproduction, energy and water budget calculated during a standard year

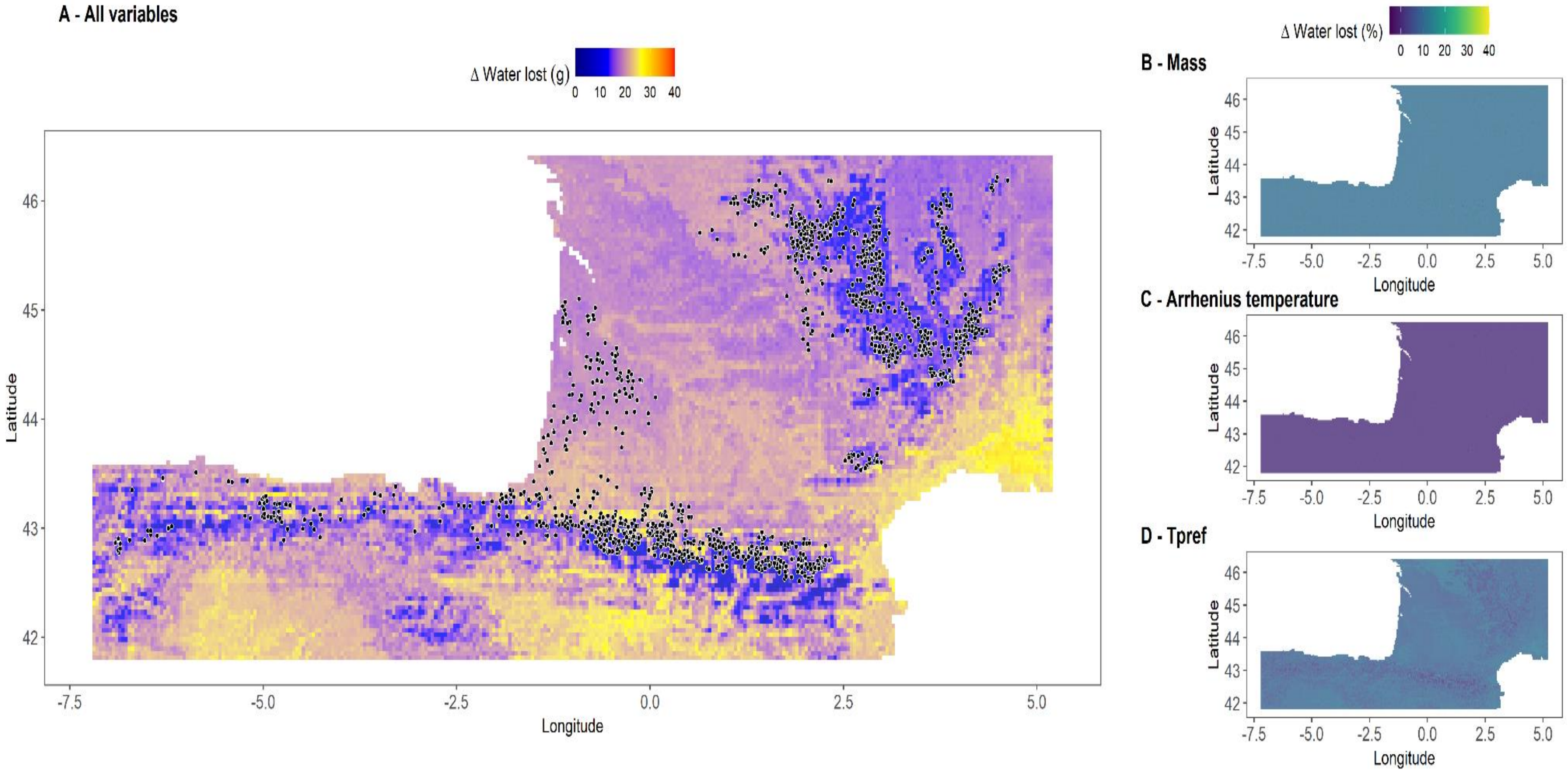


Massif Central and most European populations

Southwestern Europe (Pyrénées) and other European populations

After Dupoué et al. unpub data

Water budget of viviparity versus oviparity



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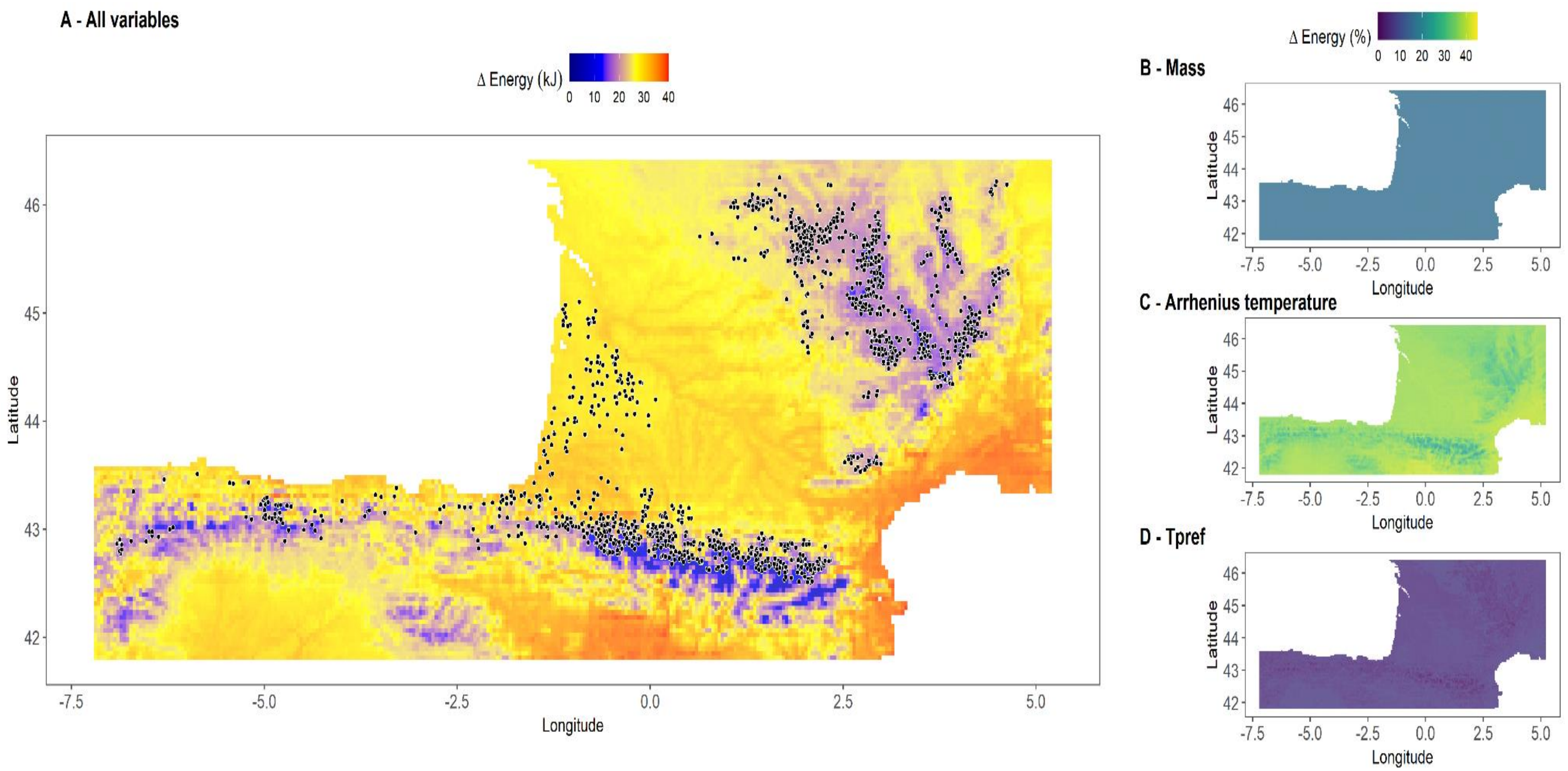

After Dupoué et al. unpub data

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ANR

AQUATHERM: The potential of hydroregulation and thermoregulation to influence ecological responses to climate change

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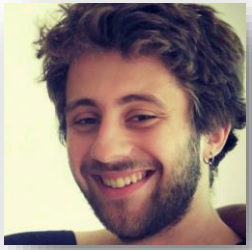

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