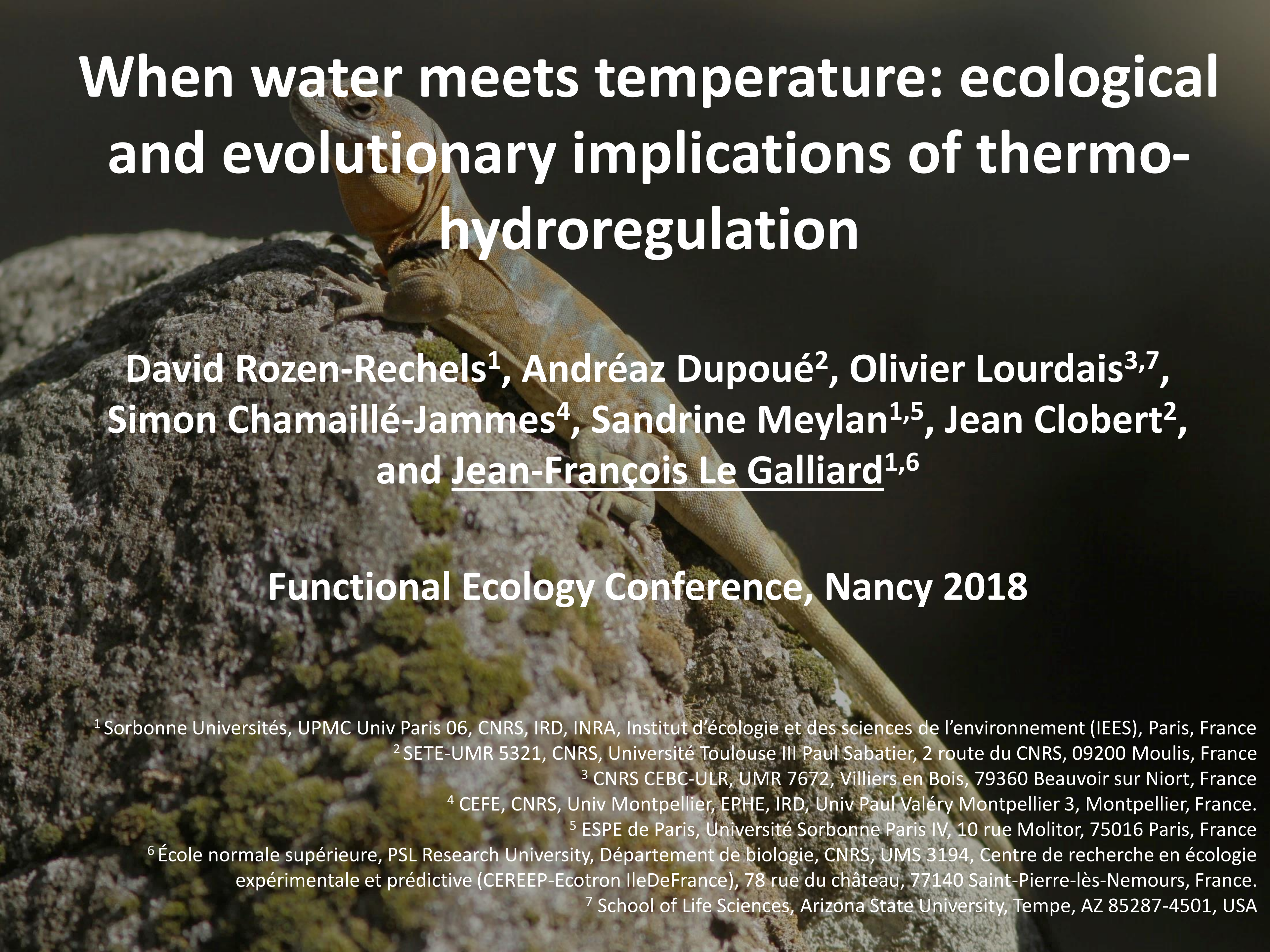


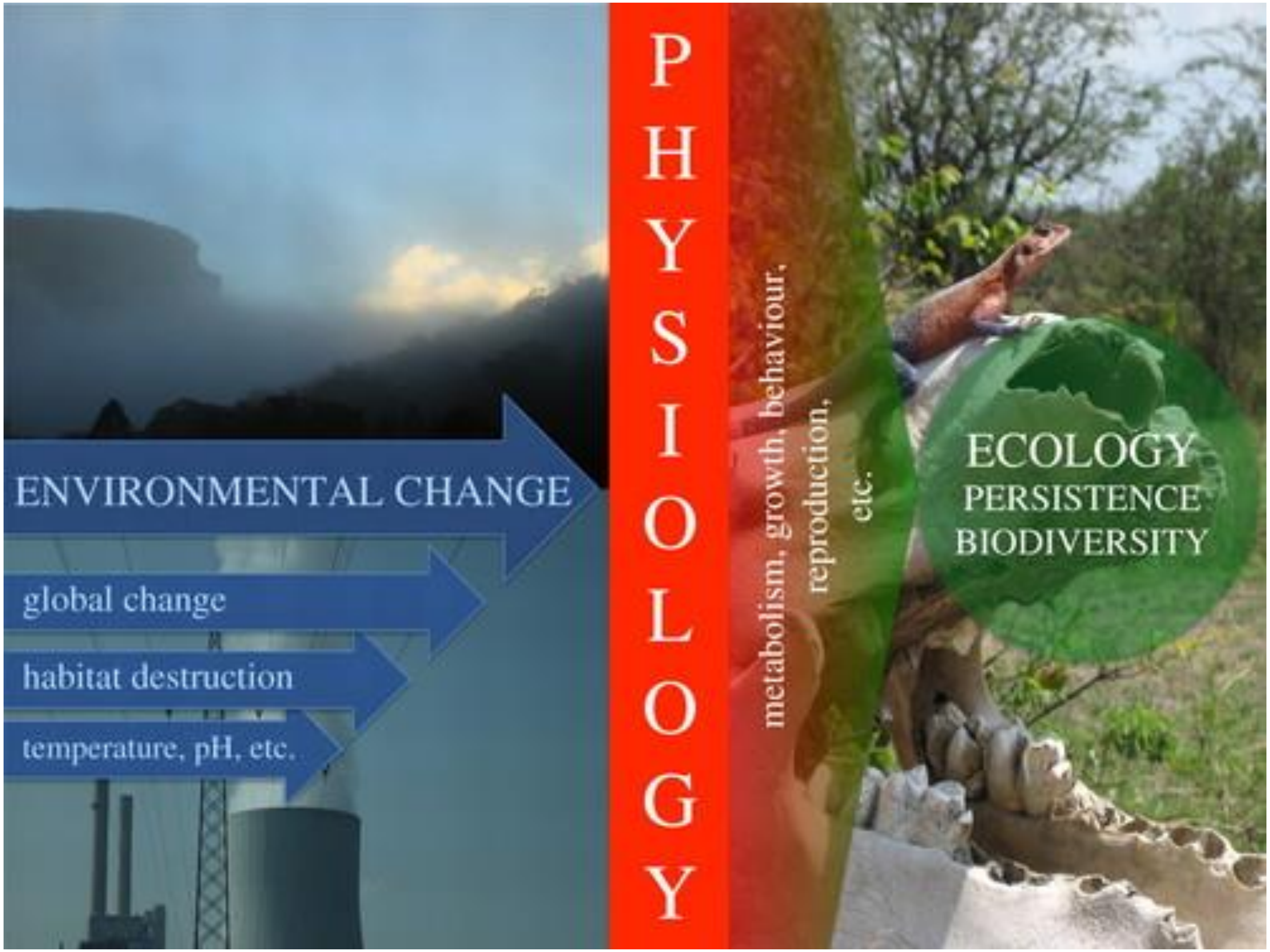
When water meets temperature: ecological and evolutionary implications of thermo-hydroregulation

David Rozen-Rechels[1], Andréaz Dupoué[2], Olivier Lourdais[3,7], Simon Chamaillé-Jammes[4], Sandrine Meylan[1,5], Jean Clobert[2], and Jean-François Le Galliard[1,6]

Functional Ecology Conference, Nancy 2018

[1] Sorbonne Universités, UPMC Univ Paris 06, CNRS, IRD, INRA, Institut d'écologie et des sciences de l'environnement (IEES), Paris, France
[2] SETE-UMR 5321, CNRS, Université Toulouse III Paul Sabatier, 2 route du CNRS, 09200 Moulis, France
[3] CNRS CEBC-ULR, UMR 7672, Villiers en Bois, 79360 Beauvoir sur Niort, France
[4] CEFE, CNRS, Univ Montpellier, EPHE, IRD, Univ Paul Valéry Montpellier 3, Montpellier, France.
[5] ESPE de Paris, Université Sorbonne Paris IV, 10 rue Molitor, 75016 Paris, France
[6] École normale supérieure, PSL Research University, Département de biologie, CNRS, UMS 3194, Centre de recherche en écologie expérimentale et prédictive (CEREEP-Ecotron IleDeFrance), 78 rue du château, 77140 Saint-Pierre-lès-Nemours, France.
[7] School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501, USA

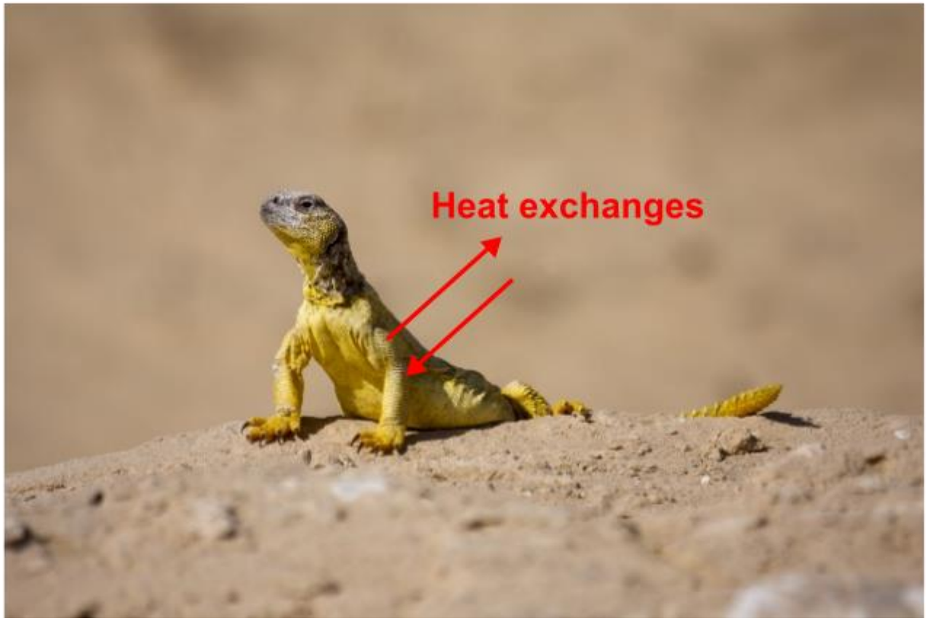
From physiology and behaviour to ecological patterns



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

Thermal biology in metazoans (animals)

Ectothermic species

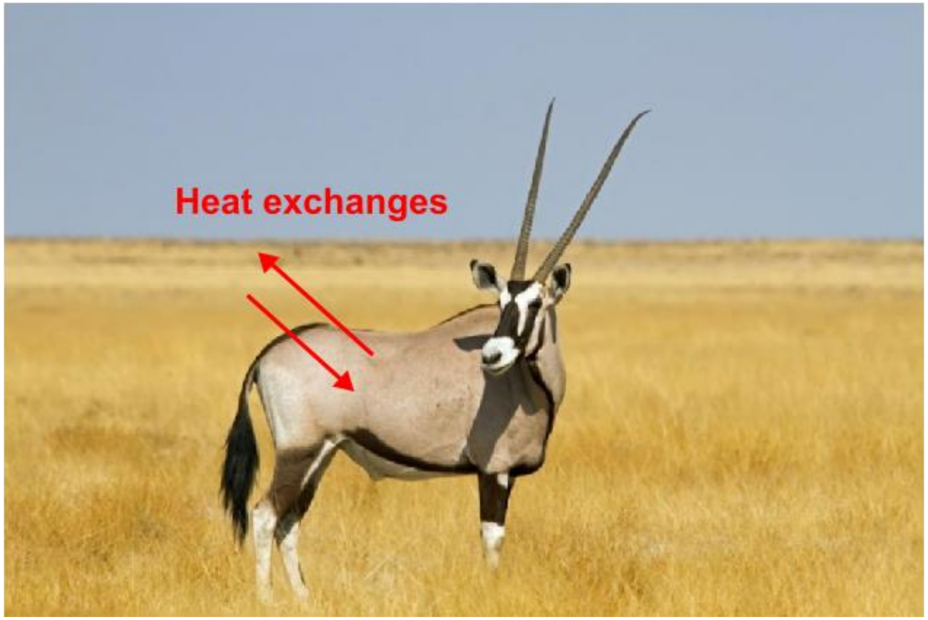


"Broad range" of body temperatures varying around a thermal preference

Behavioural regulation relying on environmental temperatures

Some evaporative cooling and metabolic heat production

Endothermic species



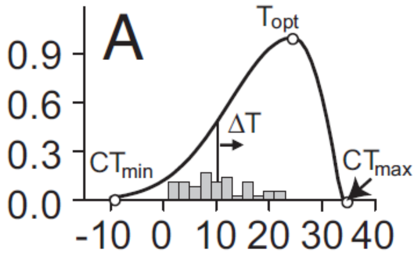
"Tightly regulated" body temperatures within a safe zone

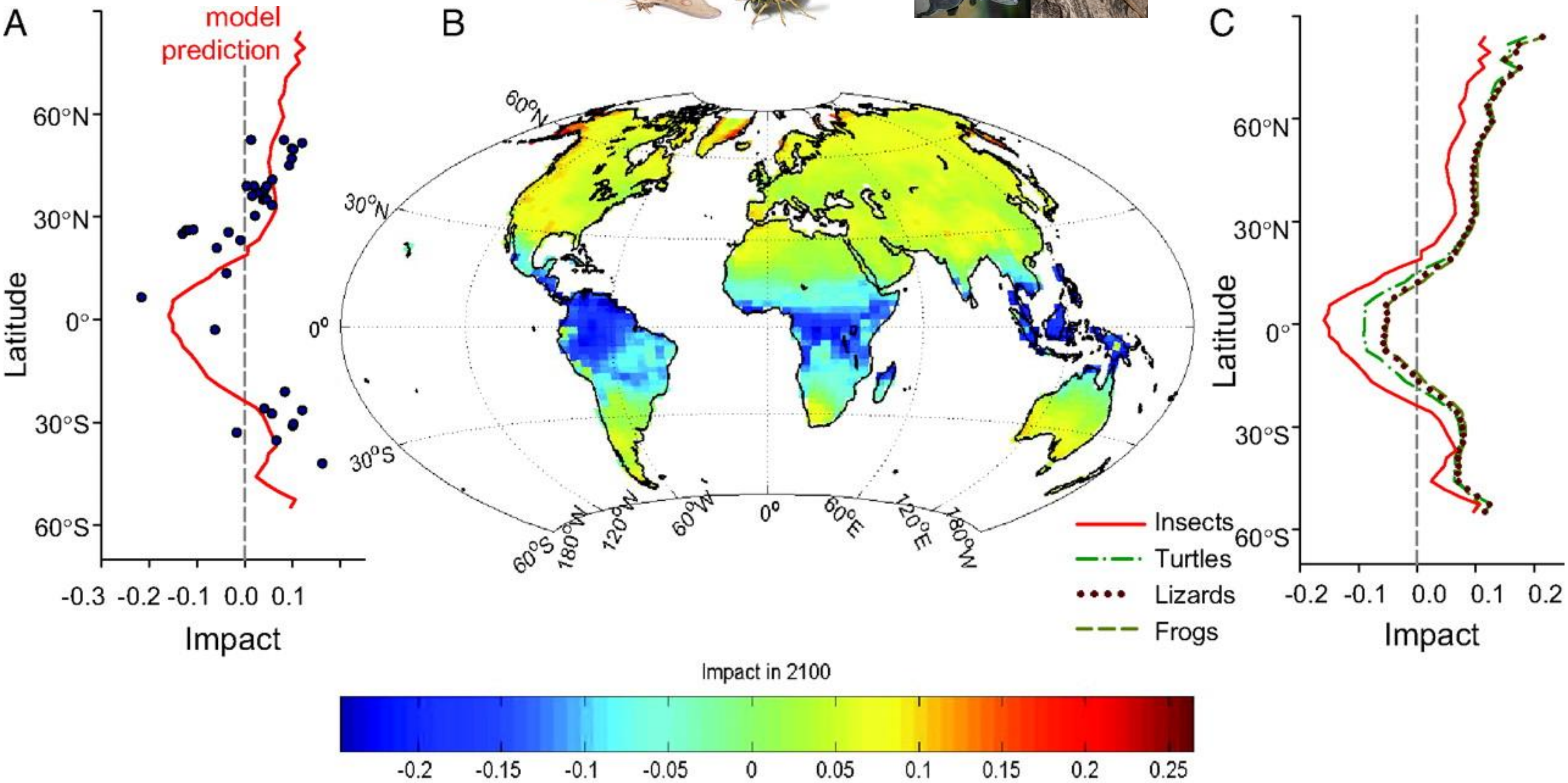
Metabolic heat production

Evaporative cooling

Some behavioural regulation

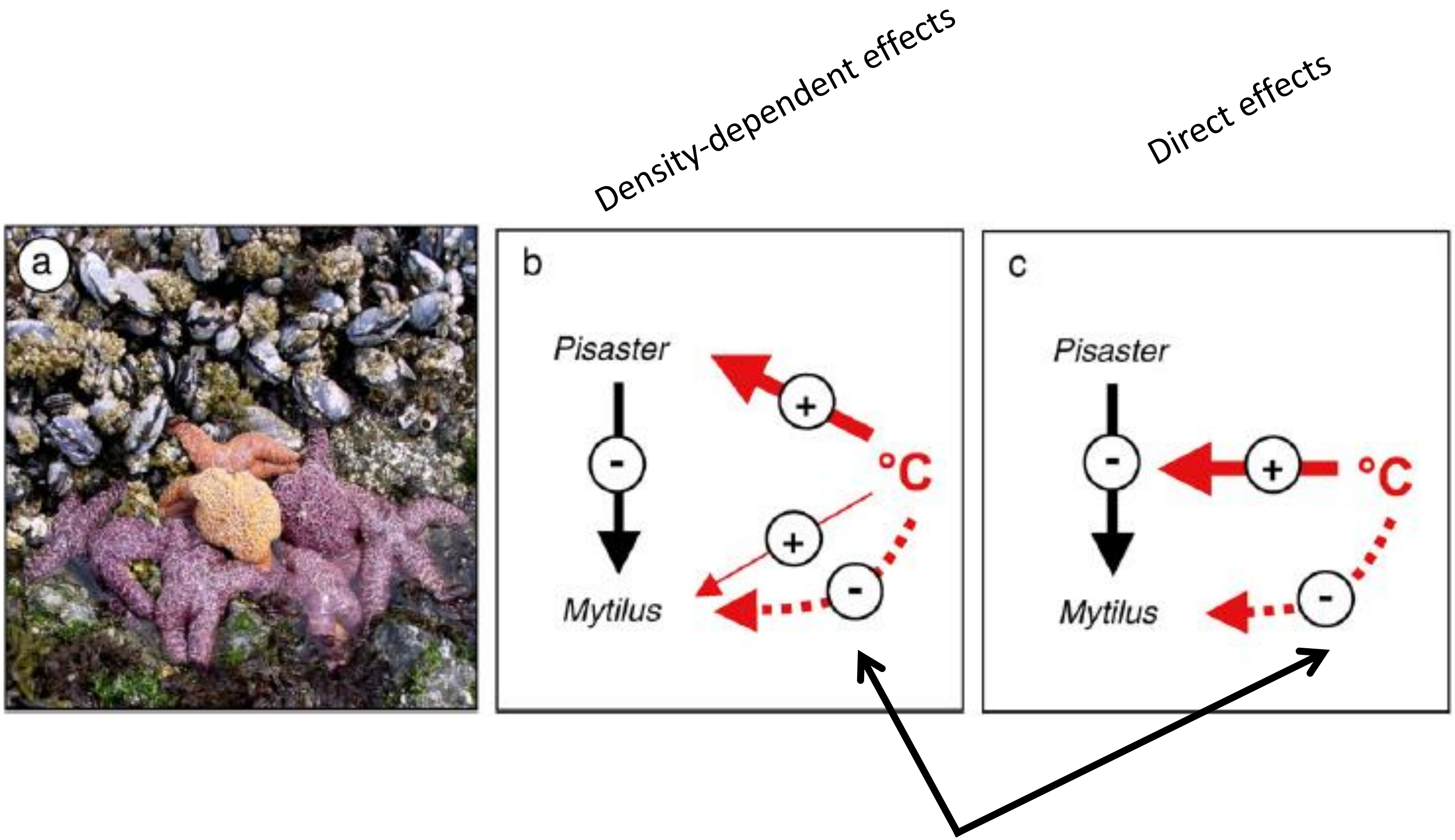
Climate warming and the need for thermoregulation





Deutsch, Tewksbury et al. Impacts of climate warming on terrestrial ectotherms across latitude. PNAS 2008, 105 (18) 6668-6672; DOI: 10.1073/pnas.0709472105

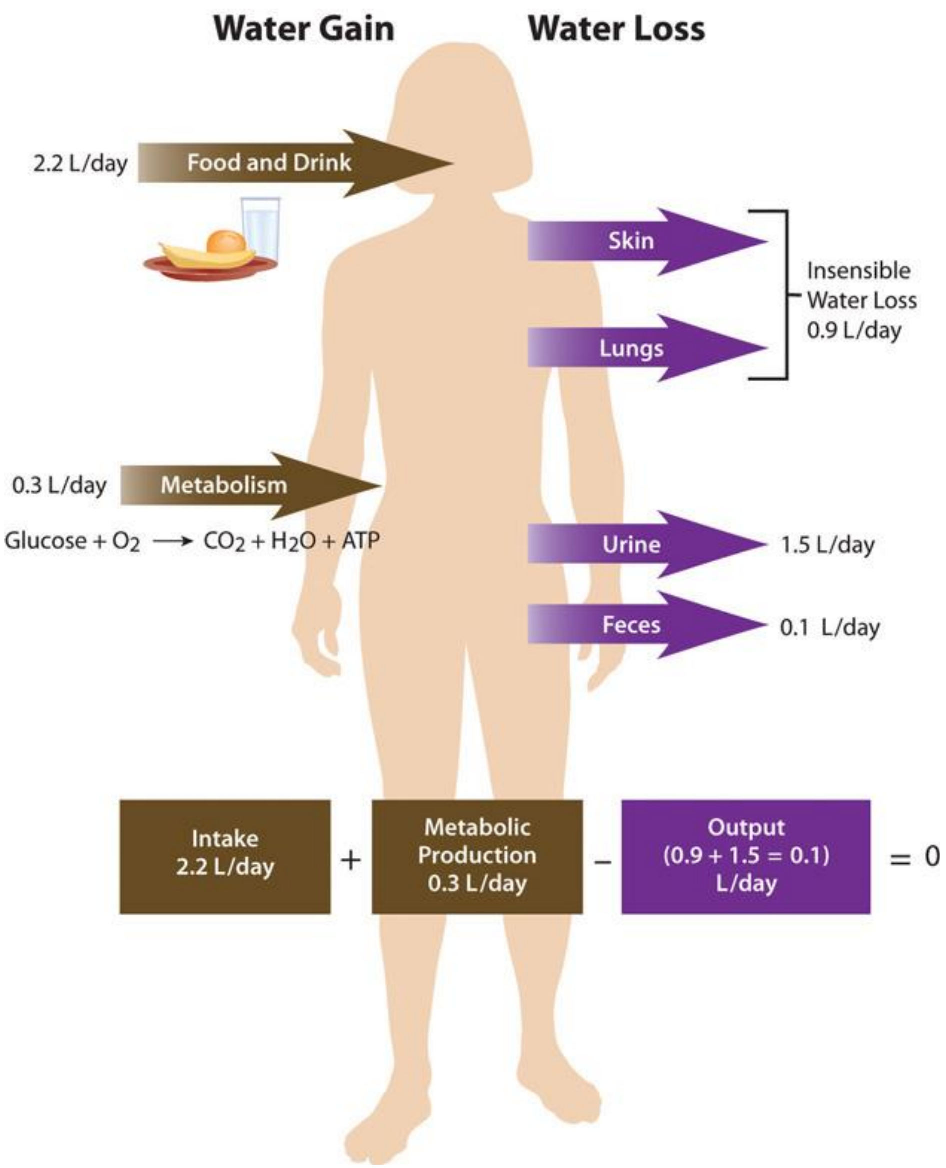
Ecosystem-level consequences of thermal biology



***Net effect on the prey population driven by the predator thermal* biology**

Kordas, R. L., Harley, C. D. G. & O'Connor, M. I. (2011) Community ecology in a warming world: The influence of temperature on interspecific interactions in marine systems. *Journal of Experimental Marine Biology and Ecology,* **400,** 218-226.

Water balance regulation in animals: a neglected component



Regulation of the water balance (hydroregulation) in animals involves

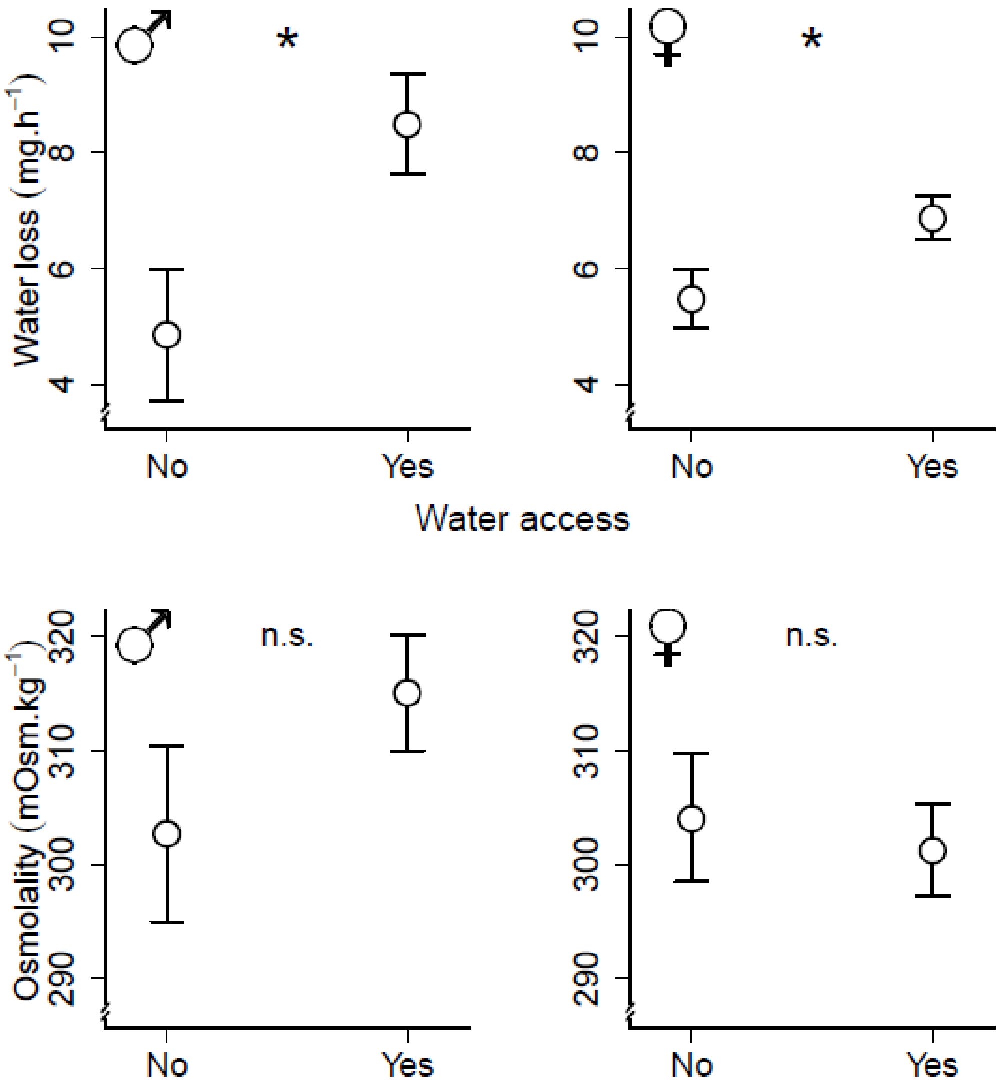
Inputs from food and free standing water = *foraging behaviour and habitat selection*

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

Water loss through the skin, lungs and urine or feces = *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)

Example of hydroregulation mechanism: skin water loss

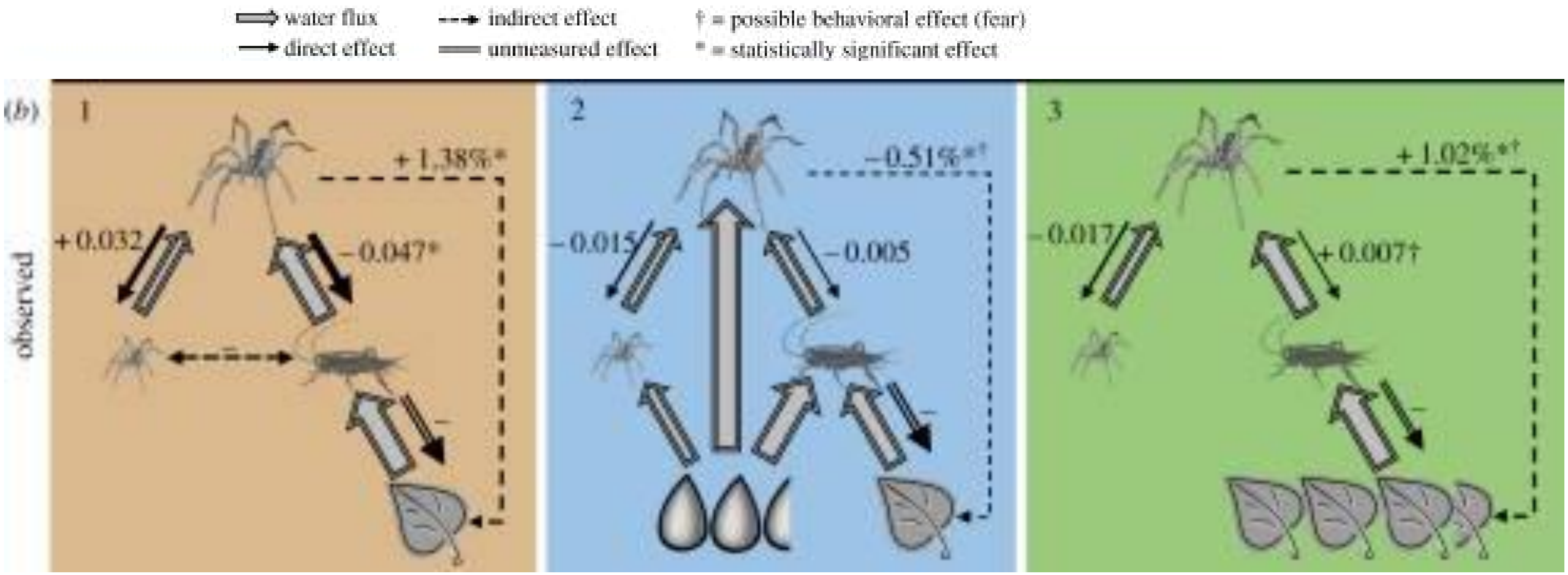


Water loss: lower standard water loss rates in habitats without access to free standing water

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

Trophic interactions and top-down effects of water imbalance



Dry natural forest (left): strong water flux from leaves to predators through grazers and a top-down control of primary production by top predators

Free standing water addition (centre): strong direct water flux to top predators, loss of top-down control of herbivores by spiders due to change in trophic cascade and effects on habitat selection by grazers

Moist leaves addition (left): strong water flux from leaves to spiders through grazers but no top-down trophic cascade

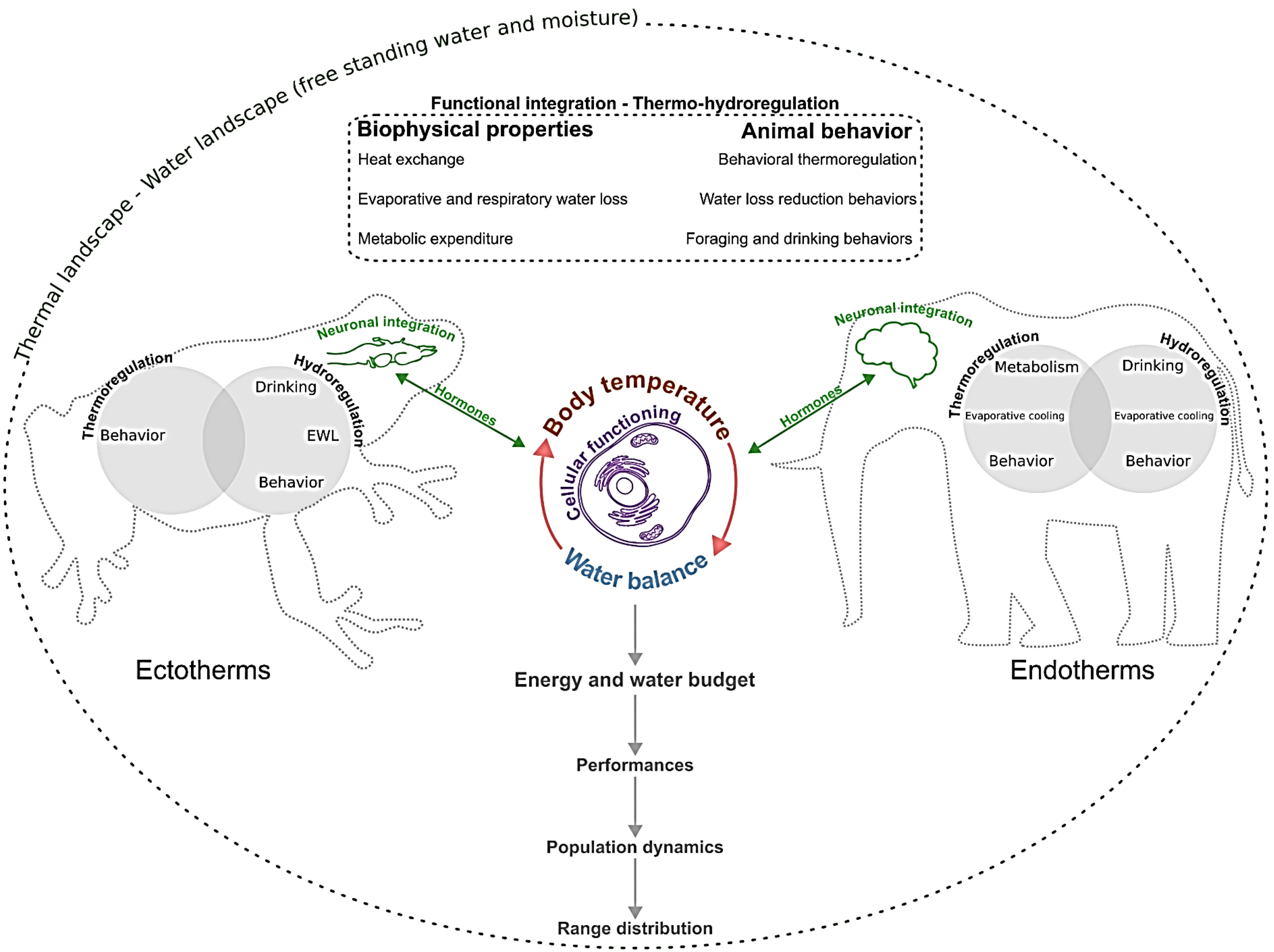
McCluney KE, Sabo JL. Animal water balance drives top-down effects in a riparian forest-implications for terrestrial trophic cascades. *Proc Biol Sci*. 2016;283(1836):20160881.

Interplays between thermoregulation and hydroregulation

- Previous studies of water and temperature regulation in animals have emphasized independent processes

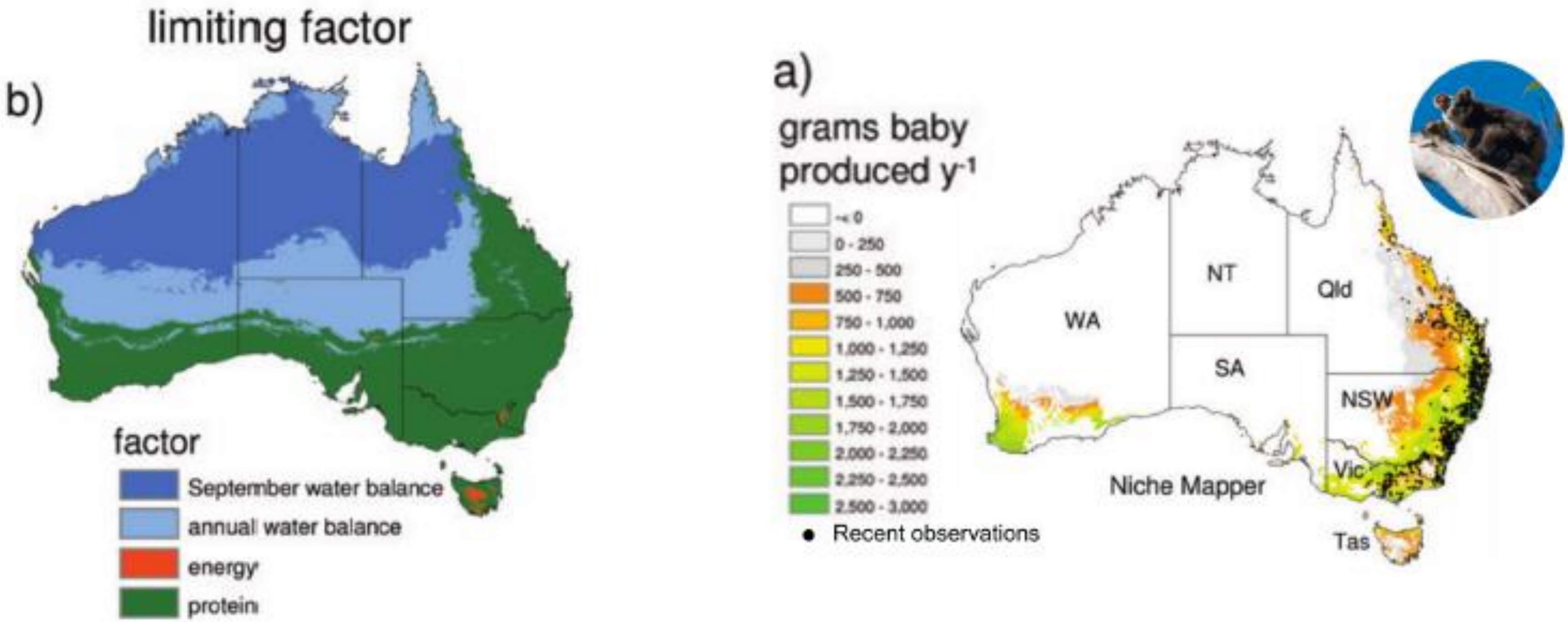
- Contra, we believe that mechanisms of thermo- and hydroregulation must also be viewed as interactive processes in wild terrestrial animals because
  1. **Environmental patterns** of water availability, rainfall and temperatures are often **correlated**
  2. **Water is a limiting factor** for many terrestrial species and biophysical mechanisms involve both water (e.g., VPD) and temperature
  3. **Biophysical mechanisms of hydro- and thermoregulation are tightly coupled**
  4. **Behavioural hydroregulation and thermoregulation overlap substantially**

The thermo-hydroregulation concept



Water is a limiting factor for terrestrial animals

Mechanistic niche model of the Australian gliding possum



Broad scale distribution largely determined by limited rainfall during the year and secondarily by energy and thermal biology

McCluney KE, Sabo JL. Animal water balance drives top-down effects in a riparian forest-implications for terrestrial trophic cascades. *Proc Biol Sci*. 2016;283(1836):20160881.

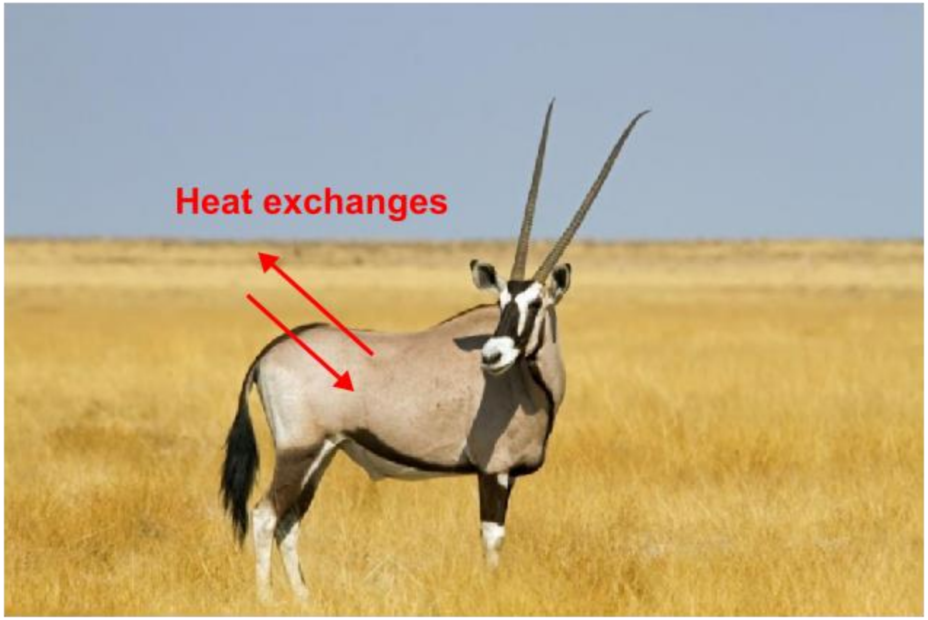
Thermal physiology interacts with hydroregulation

Thermoregulation and EWL in ectotherms

↑ body temperature
↑ dehydration
↓ water balance

Examples in reptiles, amphibians or numerous insects

Evaporative cooling in endotherms



↑ evaporative water losses
↑ dehydration
↓ water balance

Examples in desert ungulates or bird species

3. Physiological trade-offs between water and temperature regulation

Thermal consequences of gestation in viviparous reptiles

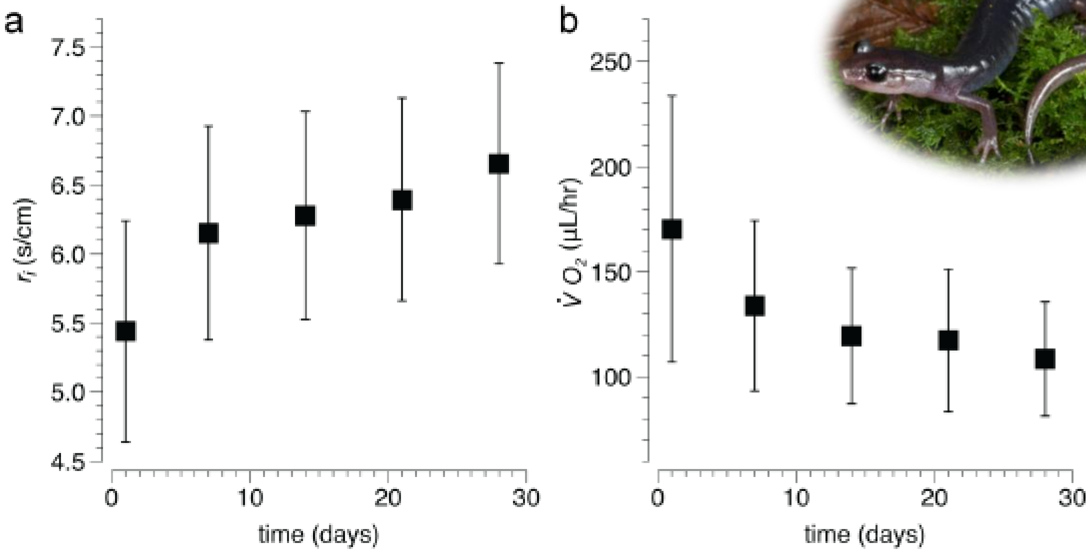
- selects for more thermoregulation effort due to strong benefits of higher and more accurate maternal thermoregulation
- leads to facultative endothermy in some snakes (pythons)
- viviparity is an adaptive response to "cold climate" conditions

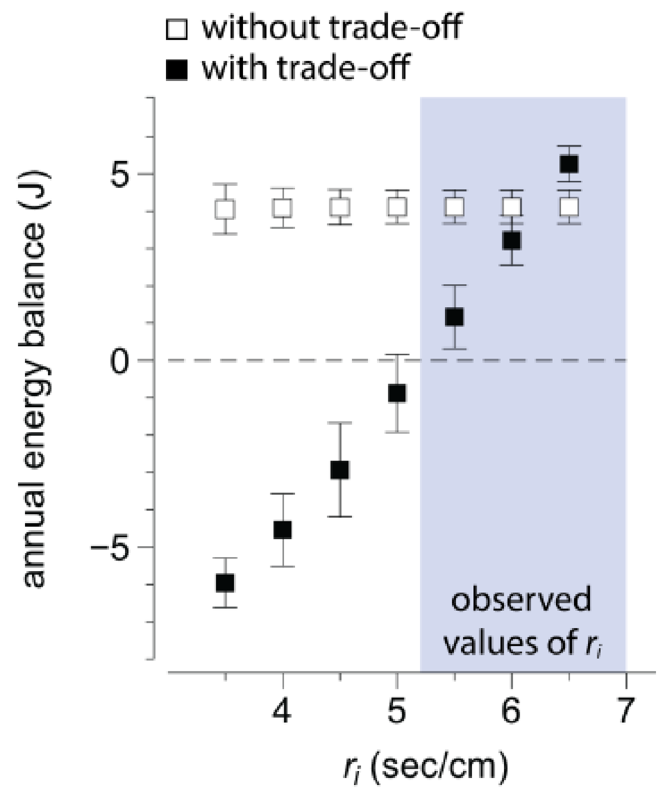
Water balance during gestation in viviparous reptiles

- concurrent need for water especially at the end of gestation
- stronger evaporative water loss during gestation due to physical burden of reproduction and thermoregulation effort
- environmental water availability might set a constraint on the evolution of viviparity in cold climate

Thermo-hydroregulation crucial to our understanding of the evolution of viviparity

3. Physiological trade-offs, acclimation and energy budget



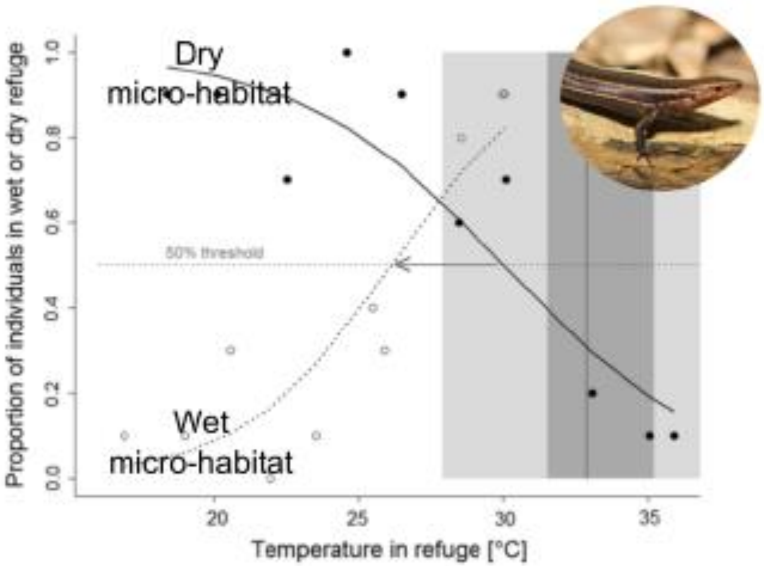


Respiratory-energy metabolism decrease and resistance to evaporative increase during warm acclimation, with individual-level analyses revealing a physiological trade-off between respiratory metabolism and water loss

Riddell EA, McPhail J, Damm JD, Sears MW. Trade-offs between water loss and gas exchange influence habitat suitability of a woodland salamander. *Funct Ecol*. 2018;32:916–925.

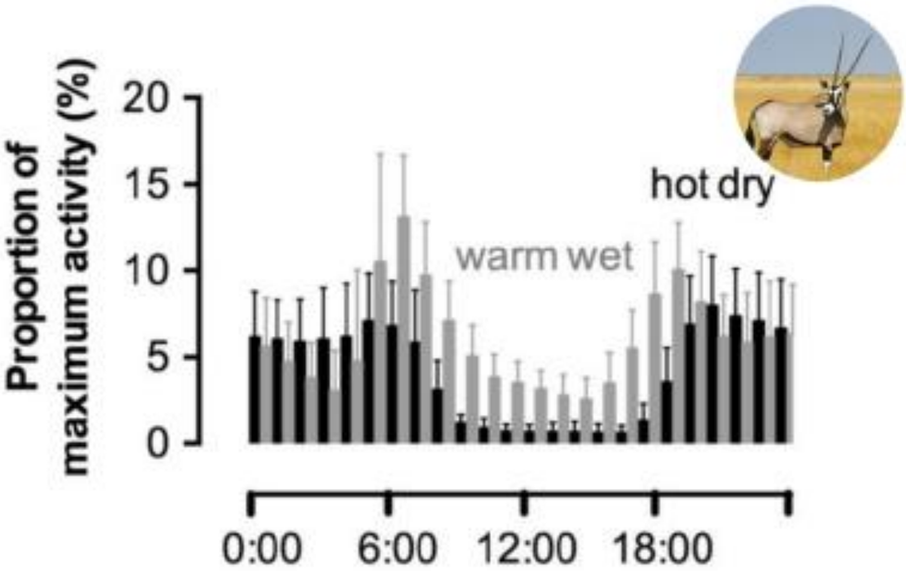
4. Behavioural thermoregulation trades off with hydroregulation

Refuge use in lizards



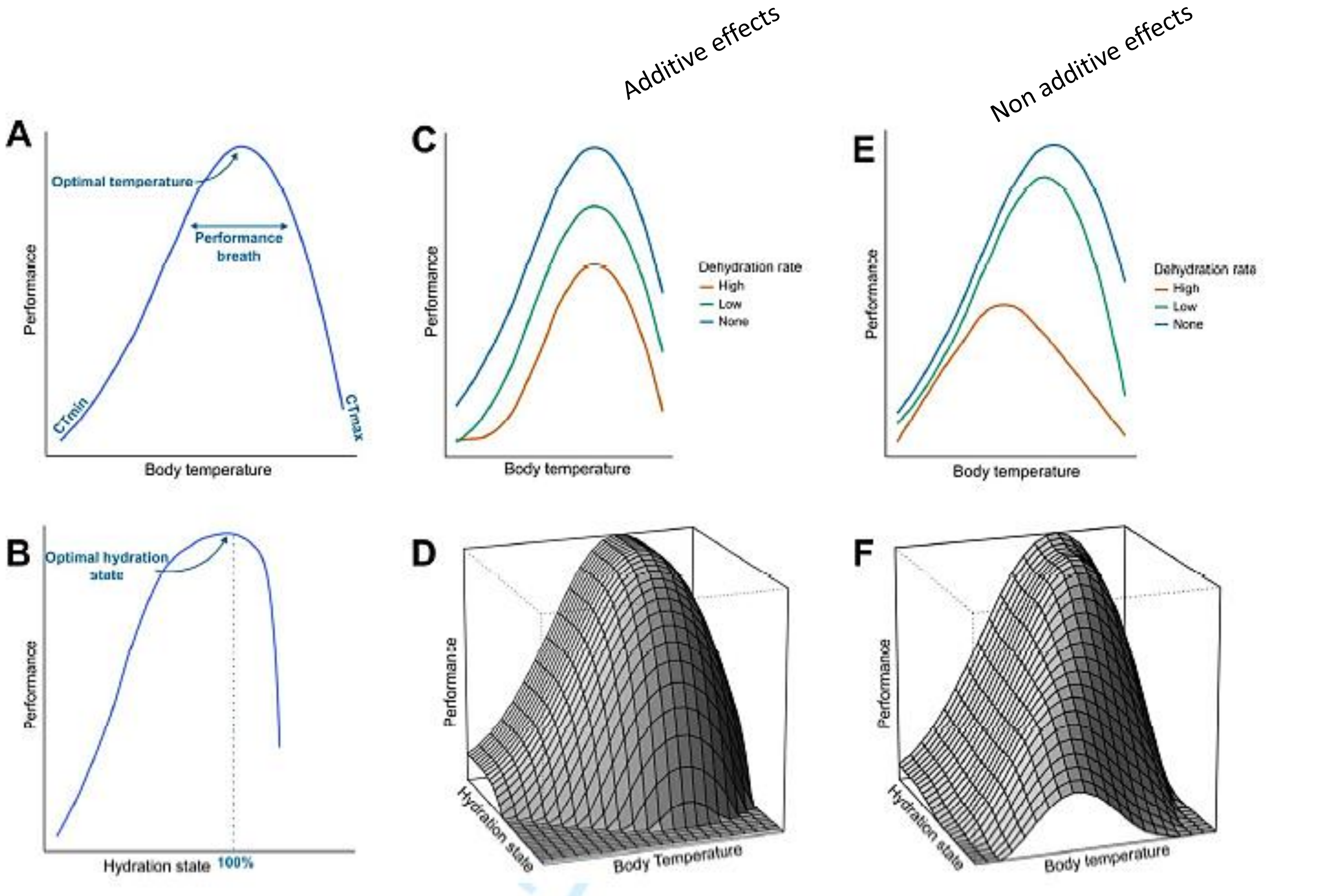
Warming increases refuge use disproportionately for moist microhabitats

Activity in desert ungulates

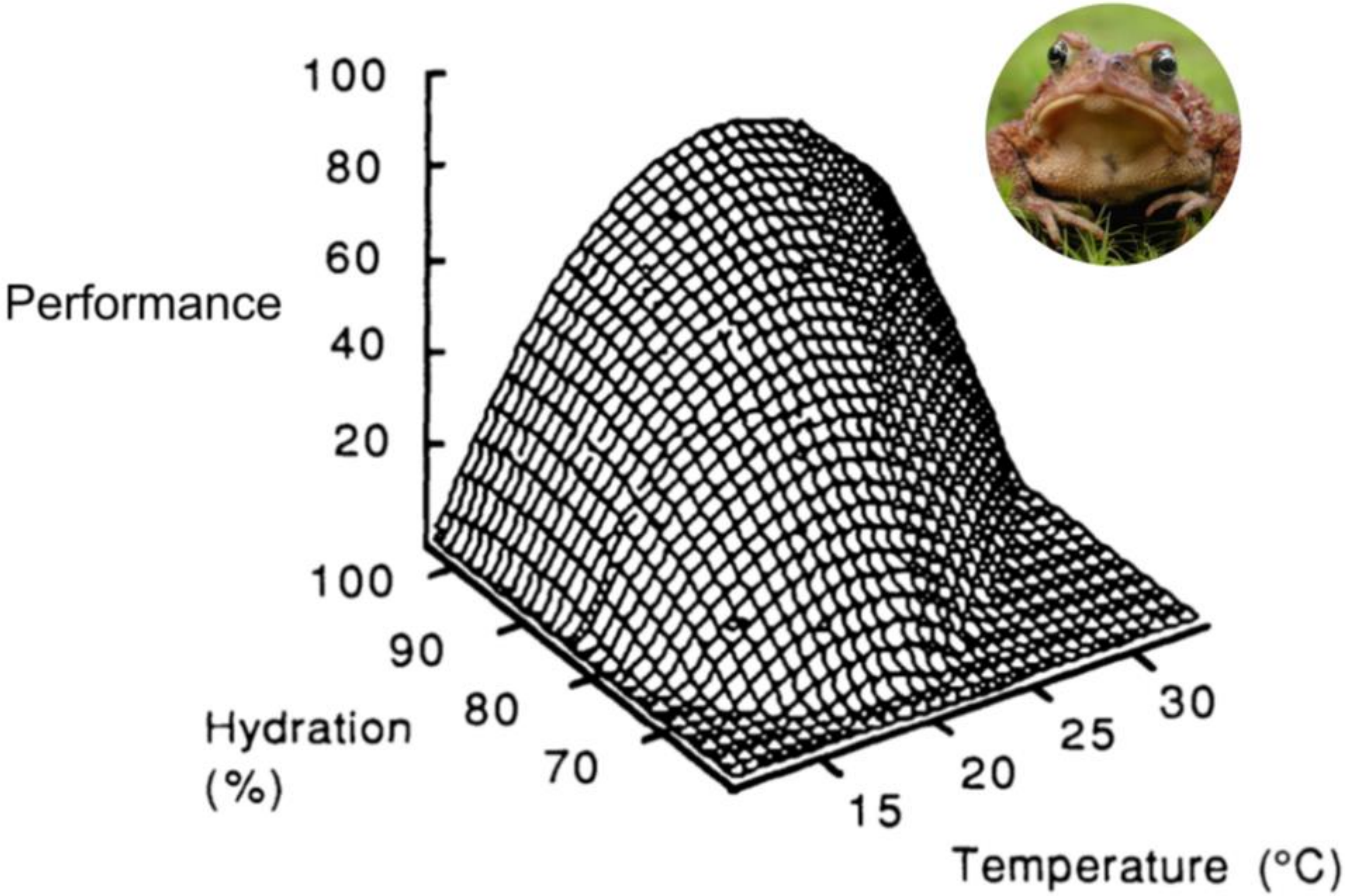


Mid-day conditions induce a loss of activity especially during dry days

Interactive effects on performance variation



Interactive effects on performance: case study



Preest M. R., & Pough F. H. (1989). Interaction of temperature and hydration on locomotion of toads. Functional Ecology, 3, 693–699.

Conclusions

- **Animal thermal and water biology both play a key role** in ecological responses to climate change and ecosystem responses to changing climate

- Thermal and water biology are **functionally integrated** and physiological or behavioural traits have evolved in terrestrial animals to cope with both thermal and water needs, especially through trade-offs between some functional traits

- The **thermo-hydroregulation concept will help** refine our mechanistic understanding of global change effects on terrestrial animals including numerous keystone species with top-down effects on ecosystem functioning

- Future studies will require **bivariate analyses of water imbalance and thermal stress** and joint experiments on water availability and thermal stress

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David Rozen-Rechels

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

CEREEP

Jean-François Le Galliard
Scientific coordinator

iEES Paris

Sandrine Meylan
Principal investigator

SETE Moulis

Jean Clobert
Principal investigator

Andréaz Dupoué
Scientific collaborator

CEBC Chizé

Olivier Lourdais
Principal investigator

CEFE Montpellier

Simon Chamaillé-Jammes
Scientific collaborator